

HAMILTON-C2

Intelligent Ventilation

Operator's Manual
PN 624131/06
Software version 2.x
October 2010



© 2010 HAMILTON MEDICAL AG. All rights reserved. Printed in Switzerland. No part of this publication may be reproduced or stored in a database or retrieval system, nor transmitted, in any form or by any means, electronic, mechanical, by photocopying, recording, or otherwise, without the prior written permission of HAMILTON MEDICAL.

This manual may be revised or replaced by HAMILTON MEDICAL at any time and without notice. Ensure that you have the most current applicable version of this manual; if in doubt, contact HAMILTON MEDICAL AG Marketing Department. While the information set forth is believed to be accurate, it is not a substitute for the exercise of professional judgment.

Nothing in this manual shall limit or restrict in any way HAMILTON MEDICAL's right to revise or otherwise change or modify the equipment (including its software) described herein, without notice. In the absence of an express, written agreement to the contrary, HAMILTON MEDICAL has no obligation to furnish any such revisions, changes, or modifications to the owner or user of the equipment (including software) described herein.

The equipment must be operated and serviced by trained professionals only. HAMILTON MEDICAL's sole responsibility with respect to the equipment and its use is as stated in the Limited Warranty provided in this manual.

Product and company names mentioned herein may be the trademarks of their respective owners.

HAMILTON MEDICAL will make available on request circuit diagrams, component parts lists, descriptions, calibration instructions, or other information that will assist the user's authorized trained personnel to repair those parts of the equipment deemed by HAMILTON MEDICAL to be repairable.

Manufacturer

HAMILTON MEDICAL AG
Via Crusch 8
CH-7402 Bonaduz
Switzerland
Phone: (+41) 81 660 60 10
Fax: (+41) 81 660 60 20
info@hamilton-medical.com
www.hamilton-medical.com

Distributor in USA

HAMILTON MEDICAL, Inc.
4990 Energy Way
P.O. Box 30008
Reno, NV 89520
Phone: (775) 858-3200
Toll-free: (800) 426-6331
Fax: (775) 856-5621
marketing@hamilton-medical.net

HAMILTON-C2 software information

The software version for the HAMILTON-C2 is visible in the **System -> Info** window. The software version for the VUP (ventilator unit processor) (that is, the digit to the left of the decimal point for VUP) should match the version on the title page of this manual. See section 3.3.1 for details.

Definitions

WARNING

Indicates a potentially hazardous situation which, if not avoided, could result in death or serious injury.

CAUTION

Indicates a potentially hazardous situation which, if not avoided, could result in minor or moderate injury.

NOTE:

Emphasizes information of particular importance.



Applies only when the neonatal option is installed.

Applies only when the CO2 sensor option is installed

CO2

Applies only when the TRC option is installed

TRC

General cautions and notes

Intended use

The HAMILTON-C2 ventilator is intended to provide positive pressure ventilatory support to adults, pediatrics, infants and neonates.

Intended areas of use:

- In the intensive care ward or in the recovery room
- During secondary transport from one hospital to another
- During transfer of ventilated patients within the hospital

The HAMILTON-C2 ventilator is a medical device intended for use by qualified, trained personnel under the direction of a physician and within the limits of its stated technical specifications.

CAUTION

(USA only): Federal law restricts this device to sale by or on the order of a physician.

NOTE:

Not all options are available in all countries.

General operation notes

- The displays shown in this manual may not exactly match what you see on your own ventilator.
- Familiarize yourself with this operator's manual before using the ventilator on a patient.
- Displayed information that is ghosted is not active and may not be selected.
- Dashes displayed in place of monitored data indicate that valid values are not yet available or do not apply.
- If a ventilator control does not respond when selected by touch or by the turn of a knob, the control is not active in this particular instance or the function is not implemented.

Monitoring and alarms

- The HAMILTON-C2 is not intended to be a comprehensive vital sign monitor for patients on life-support equipment. Patients on life-support equipment should be appropriately monitored by qualified medical personnel and suitable monitoring devices. The use of an alarm monitoring system does not give absolute assurance of warning for every form of malfunction that may occur with the ventilator. Alarm messages may not exactly pinpoint a problem; the exercise of clinical judgment is necessary.
- An alternative means of ventilation shall be available whenever the ventilator is in use. If a fault is detected in the ventilator or its life-support functions are in doubt, disconnect the HAMILTON-C2 from the patient and immediately start ventilation with such a device (for example, a resuscitation bag), using PEEP and/or increased oxygen concentration when appropriate. The ventilator must be removed from clinical use and serviced by a HAMILTON MEDICAL authorized service engineer.
- It is recommended that additional independent monitoring devices be used during mechanical ventilation. The operator of the ventilator must still maintain full responsibility for proper ventilation and patient safety in all situations.
- Do not silence the audible alarm when leaving the patient unattended.
- Do not use the exhaust port of the expiratory valve for spirometry. Due to the HAMILTON-C2's base flow, the exhaust gas output is larger than the patient's actual exhaled volume.
- Do not put a vessel filled with a liquid on the ventilator. If a liquid enters the product, a fire and/or electric shock may occur.

Fire and other hazards

- To reduce the risk of fire or explosion, do not place the ventilator in a combustible or explosive environment (for example, around flammable anesthetics or other ignition

sources). Do not use it with any equipment contaminated with oil or grease.

- To reduce the risk of fire, do not use high-pressure gas hoses that are worn or contaminated with combustible materials like grease or oil.
- To reduce the risk of fire, use only breathing circuits intended for use in oxygen-enriched environments. Do not use antistatic or electrically conductive tubing.
- In case of fire, immediately secure the patient's ventilatory needs, switch off the ventilator, and disconnect it from its gas and electrical sources.

Service and testing

- To ensure proper servicing and to prevent possible physical injury, only HAMILTON MEDICAL authorized service personnel should attempt to service the ventilator.
- To reduce the risk of electrical shock, disconnect electrical power from the ventilator before servicing. Be aware that battery power remains even after the mains is disconnected. Be aware that if the power switch is off, some parts still carry high voltage.
- Do not attempt service procedures other than those specified in the service manual.
- Use replacement parts supplied by HAMILTON MEDICAL only.
- Any attempt to modify the ventilator hardware or software without the express written approval of HAMILTON MEDICAL automatically voids all warranties and liabilities.
- The preventive maintenance program requires a general service every 5000 hours or yearly, whichever comes first.
- To ensure the ventilator's safe operation, always run the tests and calibrations prescribed in Section 3 before using the ventilator on a patient. If the ventilator fails any tests, remove it from clinical use immediately. Do not use the ventilator until necessary repairs are completed and all tests have passed.

-
- The manufacturer can only be responsible for the safety, reliability, and performance of the ventilator if:
 - appropriately trained personnel carry out assembly operations, extensions, readjustments, modifications or repairs;
 - the electrical installation of the relevant room complies with the appropriate requirements; and
 - the ventilator system is used in accordance with the operator's manual.

Electromagnetic susceptibility

The HAMILTON-C2 complies with the IEC 60601-1-2 EMC (Electro Magnetic Compatibility) Collateral Standard. It is intended for use in the electromagnetic environment described in Table A-17 through Table A-19. Do not use the HAMILTON-C2 in an environment with magnetic resonance imaging (MRI) equipment.

Units of measure

NOTE:

In this manual pressure is indicated in cmH₂O, PCO₂ in mmHg and length in cm.

On the HAMILTON-C2 pressures are indicated in cmH₂O, mbar or hPa. Hectopascals (hPa) are used by some institutions instead. Since 1 mbar equals 1 hPa, which equals 1.016 cmH₂O, the units may be used interchangeably. CO₂ is indicated in mmHg, Torr or kPa and length in cm or inch.

Disposal

Dispose of all parts removed from the device according to your institution's protocol. Follow all local, state, and federal regulations with respect to environmental protection, especially when disposing of the electronic device or parts of it (for example oxygen cell, batteries).

Year of manufacture

The year of manufacture is shown on the serial number label on the HAMILTON-C2 ventilation unit.

Table of contents

1	General information	1-1
1.1	Introduction	1-2
1.2	Functional description	1-4
1.2.1	System overview	1-4
1.2.2	Gas supply and delivery	1-5
1.2.3	Gas monitoring with the Flow Sensor	1-7
1.3	Physical description	1-9
1.3.1	Breathing circuits and accessories	1-9
1.3.2	Ventilator unit	1-13
1.3.3	Screen	1-20
1.4	Symbols used on device labels and packaging	1-22
2	Preparing for ventilation	2-1
2.1	Introduction	2-2
2.2	Installing the patient tubing support arm	2-4
2.3	Installing the humidifier	2-5
2.4	Installing the option board	2-5
2.5	Installing the patient breathing circuit	2-6
2.6	Installing the pneumatic nebulizer	2-17
2.7	Setting up for monitoring by the optional CO2 sensor	2-19
2.7.1	CO2 mainstream measurement	2-20
2.7.2	CO2 sidestream measurement	2-24
2.8	Installing the optional Aeroneb Pro nebulizer	2-26
2.9	Using an expiratory filter	2-26
2.10	Connecting to primary power source	2-27
2.10.1	Connecting to AC power	2-28
2.10.2	Connecting to DC power	2-28
2.11	About the batteries	2-30
2.12	Connecting the oxygen supply	2-32
2.13	Connecting to an external patient monitor or other device	2-33
2.14	Starting up the ventilator	2-34
2.15	Shutting down the ventilator	2-35
2.16	Display navigation guidelines	2-35
3	Tests, calibrations and utilities	3-1
3.1	Introduction	3-2
3.2	Running the preoperational check	3-4
3.3	System functions	3-6
3.3.1	Info: Viewing device-specific information	3-6

3.3.2	Tests & calib: Running sensor calibrations and the tightness test	3-7
3.3.3	Sensors on/off: Enabling/disabling O2 and CO2 monitoring	3-15
3.3.4	Setting day and night	3-16
3.3.5	Setting date and time	3-17
3.4	Utilities	3-18
3.4.1	Configuration: Configuring the ventilator	3-18
3.4.2	Data transfer: Copying event log data to a USB memory device	3-19
3.5	Alarm tests	3-21
3.5.1	High pressure	3-21
3.5.2	Low minute volume	3-22
3.5.3	Low oxygen alarm.	3-22
3.5.4	Disconnection on patient side	3-22
3.5.5	Loss of external power	3-23
3.5.6	Exhalation obstructed	3-23
3.5.7	Apnea.	3-23
4	Ventilator settings	4-1
4.1	Introduction	4-2
4.2	Patient grouping	4-2
4.3	Quick start-up settings	4-4
4.4	Patient setup.	4-4
4.5	Modes window: Setting the ventilation mode	4-6
4.6	Controls windows: Setting controls including apnea backup ventilation.	4-8
4.6.1	Adjusting and confirming control settings without mode change	4-8
4.6.2	Adjusting and confirming control settings after mode change	4-10
4.6.3	About apnea backup ventilation	4-12
4.6.4	Table of control settings, mode additions and ranges.	4-15
4.7	Alarms windows	4-22
4.7.1	Limits 1 and Limits 2: Setting alarm limits	4-23
4.7.2	Loudness: Adjusting alarm loudness	4-25
4.7.3	Buffer: Viewing alarm information	4-26
4.7.4	Table of alarm limit settings and ranges	4-27
4.7.5	TRC: Setting tube resistance compensation	4-29

5	Neonatal ventilation	5-1
5.1	Breathing circuit	5-2
5.2	Flow Sensor	5-2
5.3	Testing and calibration	5-3
5.4	Ventilation modes and mode additions	5-3
5.5	Controls	5-3
	5.5.1 Ti max	5-4
	5.5.2 Flowtrigger	5-4
	5.5.3 P-ramp	5-4
5.6	Others	5-4
6	Monitoring	6-1
6.1	Introduction	6-2
6.2	Values window: Viewing numeric patient data	6-4
6.3	Graphics window: Selecting second screen graphic	6-7
6.4	About graphic types	6-8
	6.4.1 Waveforms	6-8
	6.4.2 Dynamic Lung	6-9
	6.4.3 Vent Status	6-9
6.5	Trends	6-10
6.6	Loops	6-12
6.7	Table of monitored parameters	6-14
6.8	Freeze and cursor measurement	6-23
7	Intelligent Panels	7-1
7.1	Introduction	7-2
7.2	Dynamic Lung panel	7-2
	7.2.1 Tidal volume (Vt)	7-3
	7.2.2 Compliance (Cstat)	7-3
	7.2.3 Patient triggering: Muscle	7-3
	7.2.4 Resistance: Bronchial tree	7-4
7.3	Vent Status panel	7-5
8	Responding to alarms	8-1
8.1	Introduction	8-2
8.2	How to respond to an alarm	8-6
8.3	Alarm buffer	8-7
8.4	Events window: Reviewing the event log	8-9
8.5	Alarm troubleshooting table	8-10

9	Special functions	9-1
9.1	Standby	9-2
9.2	O2 enrichment	9-5
9.3	Suctioning tool	9-6
9.4	Manual breath/inspiratory hold	9-7
9.5	Nebulizer	9-8
9.6	Print screen	9-9
10	Maintenance	10-1
10.1	Introduction	10-2
10.2	Cleaning, disinfection and sterilization	10-2
	10.2.1 General guidelines for cleaning	10-7
	10.2.2 General guidelines for chemical disinfection	10-7
	10.2.3 General guidelines for autoclave, ETO or plasma sterilization	10-8
10.3	Preventive maintenance	10-9
	10.3.1 Servicing the air intake and fan filters	10-10
	10.3.2 Replacing the batteries	10-13
	10.3.3 Charging and calibrating the batteries	10-14
	10.3.4 Replacing the oxygen cell	10-14
10.4	Storage	10-15
10.5	Repacking and shipping	10-15
A	Specifications	A-1
A.1	Physical characteristics	A-2
A.2	Environmental requirements	A-3
A.3	Pneumatic specifications	A-3
A.4	Electrical specifications	A-4
A.5	Control settings	A-5
A.6	Monitored parameters	A-13
A.7	Alarms	A-27
A.8	Configuration specifications	A-31
A.9	Ventilator breathing system specifications	A-33
A.10	Other technical data	A-34
A.11	Standards and approvals	A-36
A.12	EMC declarations (IEC 60601-1-2)	A-37
A.13	Warranty	A-42
A.14	Miscellaneous	A-43

B	Modes of ventilation	B-1
B.1	Introduction	B-2
B.2	The biphasic concept	B-5
B.3	Mandatory modes	B-8
	B.3.1 (S)CMV+ mode or APVcmv	B-8
	B.3.2 PCV+ mode	B-11
B.4	Spontaneous modes (SPONT and NIV)	B-13
B.5	SIMV modes	B-19
	B.5.1 SIMV+ mode or APVsimv	B-20
	B.5.2 PSIMV+ and NIV-ST modes	B-23
B.6	nCPAP-PS mode	B-28
	B.6.1 Introduction	B-28
	B.6.2 Controls of nCPAP-PS	B-30
B.7	DuoPAP (Duo positive airway pressure)	B-31
	B.7.1 Introduction	B-31
	B.7.2 The many faces of DuoPAP	B-32
	B.7.3 Pressure support in DuoPAP breaths	B-33
	B.7.4 Synchronization	B-34
	B.7.5 Controls of DuoPAP	B-34
B.8	APRV (Airway pressure release ventilation)	B-36
	B.8.1 Introduction	B-36
	B.8.2 Initialization of APRV	B-37
	B.8.3 Sustained high pressure recruitment manoeuvres	B-39
	B.8.4 Controls of APRV	B-39
B.9	SAFETY mode and ambient state	B-41
C	ASV (adaptive support ventilation)	C-1
C.1	Introduction	C-2
C.2	ASV use in clinical practice	C-3
C.3	Detailed functional description of ASV	C-15
	C.3.1 Normal minute ventilation	C-15
	C.3.2 Targeted minute ventilation	C-16
	C.3.3 Lung-protective rules strategy	C-17
	C.3.4 Optimal breath pattern	C-20
	C.3.5 Dynamic adjustment of lung protection	C-24
	C.3.6 Dynamic adjustment of optimal breath pattern	C-25
C.4	Minimum work of breathing (Otis' equation)	C-26
C.5	ASV technical data	C-28
C.6	ASV Start up	C-31
C.7	References	C-32

D	NIV (non invasive ventilation)	D-1
D.1	Introduction	D-2
D.2	Benefits of noninvasive ventilation, ...	D-3
D.3	Required conditions for use.	D-4
D.4	Contraindications	D-4
D.5	Potential adverse reactions	D-5
D.6	Selecting a patient interface	D-5
D.7	Control settings	D-6
D.8	Alarms	D-7
D.9	Monitored parameters	D-8
D.10	Additional notes about using noninvasive ventilation. . . .	D-9
D.11	References	D-11
E	CO2 sensor option: Volumetric capnography	E-1
E.1	Introduction	E-2
E.2	CO2 elimination ($V'CO_2$).	E-3
E.3	End-tidal CO2 (PetCO2 and FetCO2).	E-5
E.4	Airway dead space (VDaw)	E-5
E.5	Alveolar minute ventilation ($V'alv$)	E-6
E.6	Capnogram shape (slope of the alveolar plateau, slopeCO2) . E-7	
E.7	Formulas.	E-9
E.8	References	E-10
F	Low-pressure oxygen	F-1
G	Pneumatic diagram	G-1
H	Parts and accessories	H-1
I	Communications interface	I-1
I.1	Introduction	I-2
I.2	Patient monitor	I-2
I.2.1	Patient data management system (PDMS) or other com- puter system	I-4
I.2.2	Connector pin assignments.	I-6
I.3	Nurse call	I-8
I.3.1	Inspiratory:expiratory (I:E) timing outlet.	I-8
I.3.2	Remote alarm outlet.	I-9
I.3.3	Connector pin assignments.	I-10

J	Configuration	J-1
J.1	Introduction	J-2
J.2	Accessing configuration	J-2
J.3	General: Selecting the language, units of measure and oxygen source	J-3
J.3.1	Language: Selecting the default language	J-3
J.3.2	Units: Selecting the default unit of measure for pressure display, CO2 and length.	J-3
J.3.3	More: Selecting the oxygen source and enabling the communications interface	J-4
J.4	Graphics window.	J-5
J.4.1	MMP: Selecting the default main monitoring parameter display.	J-5
J.5	Setup window (quick start-up settings).	J-6
J.5.1	Use setups: Define the default quick start-up settings	J-6
J.5.2	Use setups: Configure the quick start-up settings.	J-7
J.6	Transfer window	J-12
J.7	Options windows.	J-13
	Glossary.	Glossary-1
	Index	Index-1
	User Notes.	User Notes-1

List of Figures

1-1	Gas delivery in the HAMILTON-C2	1-6
1-2	Flow Sensor	1-8
1-3	HAMILTON-C2 with accessories	1-10
1-4	Front view	1-13
1-5	Rear view	1-16
1-6	Left side view	1-17
1-7	Right side view	1-18
1-8	Default (basic) screen	1-20
2-1	Installing the patient tubing support arm and humidifier	2-4
2-2	Option board	2-6
2-3	Patient breathing circuit for use with inspiratory heater wire (Pediatric/Adult) - (In place of the flex tube shown, a 15 x 22 adapter may be used to attach the Flow Sensor to the ET tube.)	2-9
2-4	Patient breathing circuit for use without heater wires (Pediatric/Adult) - (In place of the flex tube shown, a 15 x 22 adapter may be used to attach the Flow Sensor to the ET tube.)	2-10
2-5	Patient breathing circuit for use with HME (Pediatric/Adult) - (In place of the flex tube shown, a 15 x 22 adapter may be used to attach the Flow Sensor to the HME or ET tube.)	2-11
2-6	Patient breathing circuit with inspiratory heater wire for use with nC-PAP-PS (non-invasive ventilation neonatal) - (Use a 15M x 15F adapter to connect the infant flow sensor.)	2-12
2-7	Patient breathing circuit with inspiratory heater wire (invasive ventilation neonatal) - (Use a 15M x 15F adapter to connect the infant flow sensor.)	2-13
2-8	LiteCircuit (single-limb) patient breathing circuit (non-invasive ventilation Pediatric/Adult) - (For use with NIV or NIV-ST)	2-14
2-9	Installing the expiratory valve	2-15
2-10	Installing the Flow Sensor	2-16
2-11	Installing a pneumatic nebulizer	2-18
2-12	Connecting the CO2 sensor	2-22
2-13	Attaching the CO2 sensor to the airway adapter	2-22
2-14	Connecting the CO2 sensor/airway adapter to the patient circuit	2-23
2-15	Inserting the sample cell into the receptacle	2-25
2-16	Attaching the CO2 sensor to the airway adapter	2-25
2-17	Installing the Aeroneb Pro nebulizer	2-26
2-18	Car adapter	2-29

2-19	Power source symbols and battery charge indicator	2-31
2-20	Oxygen inlet fittings	2-33
2-21	Power switch.	2-34
3-1	Info window	3-7
3-2	Tests & calib window.	3-8
3-3	Disconnection of the mainstream sensor for calibration	3-14
3-4	Disconnection of the sidestream sensor for calibration.	3-14
3-5	Sensor on/off window	3-16
3-6	Day/Night window	3-17
3-7	Date&Time window.	3-18
3-8	Data transfer window 1	3-20
3-9	Data transfer window 2	3-21
4-1	Quick start-up settings (Example).	4-4
4-2	Patient setup window	4-5
4-3	Patient setup window neonatal	4-6
4-4	Modes window	4-7
4-5	Basic (Controls) window	4-9
4-6	More window	4-10
4-7	TRC window	4-11
4-8	Basic window during mode change (ASV mode change)	4-12
4-9	Automatic button	4-14
4-10	Limits 1 window	4-24
4-11	Limits 2 window	4-25
4-12	Loudness window	4-26
4-13	TRC window	4-30
4-14	Ptrach and Paw waveforms (with TRC active).	4-31
6-1	HAMILTON-C2 screen	6-3
6-2	Values window 1.	6-4
6-3	Values window 2.	6-5
6-4	Values window 3.	6-6
6-5	CO2 window.	6-7
6-6	Graphics window	6-8
6-7	Pressure waveform display.	6-9
6-8	Trends window	6-10
6-9	Trend display.	6-11
6-10	Loop window	6-12
6-11	Loop display	6-13
6-12	Freeze function	6-24
7-1	Dynamic Lung panel	7-2
7-2	Compliance shown by the Dynamic Lung	7-3

7-3	Patient triggering shown by the Dynamic Lung muscle	7-4
7-4	Rinsp shown by the bronchial tree of the Dynamic Lung.	7-4
7-5	Vent Status panel	7-6
8-1	Visual alarm indications	8-4
8-2	Safety ventilation screen.	8-5
8-3	Ambient state	8-6
8-4	Alarm buffer with active alarms	8-8
8-5	Alarm buffer with inactive alarms.	8-9
8-6	Events window.	8-10
9-1	Special function keys	9-3
9-2	Activate Standby window.	9-4
9-3	Standby window	9-5
10-1	Removing the filter cover	10-11
10-2	Removing the air intake filters	10-12
10-3	Removing battery 2	10-13
10-4	Replacing the oxygen cell	10-15
A-1	HAMILTON-C2 dimensions.	A-2
B-1	Conventional pressure-controlled ventilation in a passive patient. Flow to patient during inspiration (I); flow from patient during exha- lation (E) only.	B-6
B-2	Conventional pressure-controlled ventilation in an active patient when the trigger is off. Pressure increases when the patient tries to exhale (E) and pressure decreases when the patient tries to inspire (I), as valves are closed.	B-7
B-3	Biphasic PCV+ in an active patient when trigger is off. The patient can freely inspire and exhale during any phase of ventilation (+). . . .	B-8
B-4	(S)CMV+ basic controls	B-9
B-5	(S)CMV+ more controls	B-10
B-6	Breath delivery by the adaptive volume controller.	B-11
B-7	PCV+ basic controls	B-12
B-8	PCV+ more controls	B-13
B-9	SPONT basic controls	B-14
B-10	SPONT more controls	B-15
B-11	SPONT apnea controls	B-16
B-12	NIV basic controls.	B-17
B-13	NIV more controls	B-18
B-14	NIV apnea controls.	B-19
B-15	Breath timing in SIMV+	B-20
B-16	SIMV+ basic controls	B-21
B-17	SIMV+ more controls	B-22

B-18	SIMV+ apnea controls	B-23
B-19	Breath timing in PSIMV+ and NIV-ST	B-24
B-20	PSIMV+ basic controls	B-25
B-21	PSIMV+ more controls	B-26
B-22	NIV-ST basic controls	B-27
B-23	NIV-ST more controls	B-28
B-24	Breath timing in nCPAP-PS	B-29
B-25	nCPAP-PS basic controls	B-30
B-26	nCPAP-PS more controls	B-31
B-27	DuoPAP pressure curve	B-32
B-28	Pressure support in DuoPAP	B-33
B-29	DuoPAP basic controls	B-34
B-30	DuoPAP more controls	B-35
B-31	DuoPAP apnea controls	B-36
B-32	APRV breath timing	B-37
B-33	APRV basic controls	B-39
B-34	APRV more controls	B-40
B-35	APRV apnea controls	B-41
B-36	Display SAFETY mode	B-42
C-1	Clinical use of ASV. The numbers in parentheses are step numbers, which are explained in the next subsections.	C-4
C-2	ASV basic controls	C-5
C-3	ASV more controls	C-6
C-4	Hypothetical example of high %MinVol setting incompatible with the lung-protective rules strategy. The open circle denotes the actual target, the closed triangle (never shown on the ventilator) denotes the (energetically) optimal target according to Otis' equation. The HAMILTON-C2 will alarm and inform the user that the ASV target cannot be achieved.	C-11
C-5	ASV target graphics window	C-12
C-6	Normal minute ventilation as a function of ideal body weight (IBW). For adult patients, minute ventilation is calculated as $0.1 \text{ l/kg} \times \text{IBW}$ (solid line). For pediatric patients, the value indicated by the dotted line is used. Minute ventilation for a 15 kg patient thus is calculated as $0.2 \text{ l/kg} \times 15 \text{ kg} = 3 \text{ l/min}$	C-15
C-7	MinVol = 7 l/min. All possible combinations of V_t and f which result in a minute ventilation of 7 l/min lie on the bold line.	C-16
C-8	Lung-protective rules strategy to avoid high tidal volumes and pressures (A), low alveolar ventilation (B), dynamic hyperinflation or breath stacking (C), and apnea (D)	C-17

C-9	Anatomy of the ASV target graphics window. The rectangle shows the safety limits; the circle shows the target breath pattern. . .	C-21
C-10	Example of a situation after the three initial breaths. The patient symbol marks the actual measured values for Vt and rate.	C-23
C-11	Lung-protective limits are changed dynamically and according to the respiratory system mechanics. However, the limits derived from the operator input are never violated.	C-24
C-12	Changes of target values in broncho-constriction. For clarity, the safety limits are omitted. For clinical examples, see Belliato 2000. . .	C-26
C-13	Three different relationships between rate and WOB are plotted for a hypothetical lung: (+) purely resistive load causes WOB to rise with rate, (x) purely elastic load creates highest load at low rates, (o) the total lung shows a clear minimum which can be calculated according to the equation below.	C-27
E-1	Typical capnogram of patient on pressure-controlled ventilation, showing fractional concentration of CO2 plotted against time. . . .	E-3
E-2	Typical spirogram of a patient on pressure-controlled ventilation (same breath as shown in Figure E-1).	E-4
E-3	Combination of capnogram and spirogram (that is, fractional end-tidal CO2 concentration plotted against volume).	E-4
E-4	Interpretation of volumetric capnogram.	E-6
G-1	Pneumatic diagram	G-1
H-1	Ventilator parts and accessoires - standard trolley.	H-1
H-2	Ventilator parts and accessoires - standard trolley.	H-2
I-1	HAMILTON-C2 connected to a patient monitor	I-3
I-2	HAMILTON-C2 connected to a computer system	I-5
I-3	RS-232 connector pinout	I-6
I-4	RS-232 cable (PN 157354) wiring diagram	I-7
I-5	HAMILTON-C2 connected to an external device through the Special connector	I-8
I-6	Remote alarm relay positions	I-10
I-7	Interface connectors.	I-11
J-1	Language configuration window	J-3
J-2	Units configuration window.	J-4
J-3	More configuration window.	J-5
J-4	MMP configuration window.	J-6
J-5	Default setups configuration window.	J-7
J-6	Setup > patient configuration window.	J-8
J-7	Mode controls configuration window.	J-9
J-8	Mode controls configuration window	

	(Vt/IBW)	J-9
J-9	Alarms configuration window	J-10
J-10	Vent Status configuration window	J-10
J-11	Vent Status intelligent panel	J-11
J-12	Transfer window	J-12
J-13	Software options window	J-13
J-14	Hardware options window	J-14

List of Tables

1-1	Compatible parts and accessories	1-11
1-2	Symbols used on device labels and packaging	1-22
2-1	Breathing circuit parts according to patient height or IBW	2-8
2-2	Tracheal tubes and CO ₂	2-8
3-1	When to perform tests and calibrations	3-2
4-1	Patient grouping	4-3
4-2	Control settings, mode additions and ranges	4-15
4-3	Alarm limit settings and ranges	4-27
6-1	Monitored parameters	6-15
7-1	Dynamic Lung normal values	7-5
7-2	Vent Status parameters	7-6
8-1	Alarm indications in HAMILTON-C2	8-3
8-2	Alarms and other messages	8-11
10-1	Decontamination methods for HAMILTON-C2 parts.	10-4
10-2	Preventive maintenance schedule	10-9
A-1	Physical characteristics	A-2
A-2	Environmental requirements.	A-3
A-3	Pneumatic specifications.	A-3
A-4	Electrical specifications	A-4
A-5	Control setting ranges and resolutions (adult).	A-5
A-6	Control setting ranges and resolutions (neonatal).	A-8
A-7	Controls active in HAMILTON-C2 ventilation modes	A-12
A-8	Monitored parameter ranges, resolutions and accuracies (adult).	A-13
A-9	Monitored parameter ranges, resolutions and accuracies (neonatal).	A-19
A-10	Real-time curves and loops (adult)	A-25
A-11	Real-time curves and loops (neonatal).	A-26
A-12	Adjustable alarm ranges and resolutions (adult)	A-27
A-13	Adjustable alarm ranges and resolutions (neonatal)	A-29
A-14	Configuration specifications	A-31
A-15	Ventilator breathing system specifications	A-33
A-16	Other technical data.	A-34
A-17	Guidance and manufacturer's declaration – electromagnetic emis- sions	A-37
A-18	Guidance and manufacturer's declaration – electromagnetic immuni- ty	A-38

A-19	Recommended separation distances between portable and mobile RF communications equipment and the HAMILTON-C2 ventilator	A-41
B-1	Classification of HAMILTON-C2 ventilation modes	B-3
B-2	Control parameters for initialization of APRV	B-38
B-3	Safety mode settings	B-43
C-1	Blood gas and patient conditions and possible adjustments for ASV	C-10
C-2	Interpretation of breathing pattern at 100 % MinVol setting	C-13
C-3	Interpretation of breathing pattern at much higher than 100% MinVol setting	C-13
C-4	Interpretation of breathing pattern at much lower than 100% MinVol setting	C-14
C-5	ASV technical data	C-28
C-6	Initial breath pattern for Adult settings	C-31
C-7	Initial breath pattern for Pediatric settings	C-31
E-1	Examples of "normal" or expected values in mechanically ventilated patients	E-7
H-1	Ventilator parts and accessories	H-3
I-1	Interfacing hardware for patient monitors	I-4
I-2	Requirements for interfacing PDMSs	I-5
I-3	Interface connector pin assignments	I-11

1 General information

1.1	Introduction	1-2
1.2	Functional description	1-4
1.2.1	System overview	1-4
1.2.2	Gas supply and delivery	1-5
1.2.3	Gas monitoring with the Flow Sensor	1-7
1.3	Physical description	1-9
1.3.1	Breathing circuits and accessories	1-9
1.3.2	Ventilator unit	1-13
1.3.3	Screen	1-20
1.4	Symbols used on device labels and packaging	1-22

1.1 Introduction

NOTE:

The infant and neonatal module as well as tube resistance compensation (TRC) may not be installed in older devices (sold before August 2010).

The HAMILTON-C2 is designed for intensive care ventilation of adult, pediatric, infant and neonatal patients.

Ventilation modes. This full-functioned intensive care ventilator offers a complete range of modes. PCV+, PSIMV+, and SPONT are conventional pressure-controlled modes. (S)CMV+ and SIMV+, delivered by an adaptive volume controller, combine the attributes of pressure-controlled with volume-targeted ventilation. DuoPAP and APRV are two related forms of pressure ventilation designed to support spontaneous breathing on two alternating levels of CPAP. ASV[®] (adaptive support ventilation) guarantees that the patient receives the selected minute ventilation with the optimal breath pattern (lowest pressure and volume, optimal rate to minimize work of breathing and intrinsic PEEP). NIV (noninvasive ventilation) and NIV-ST (spontaneous/timed noninvasive ventilation) provide pressure support ventilation through a mask or other noninvasive interface. nCPAP-PS provides pressure support ventilation through nasal interface for infants and neonates.

Patient-triggered breaths are flow triggered.

Monitoring. The HAMILTON-C2 offers a variety of monitoring capabilities. It displays monitored parameters as numbers. You can also see this data graphically, as a combination of real-time waveforms (curves), Loops, Trends and special Intelligent Panels. These Intelligent Panels include the Dynamic Lung, which shows the lung's activity, and the Vent Status, which indicates the patient's level of ventilator dependency. The HAMILTON-C2's monitored data is based on pressure and flow measurements collected by the HAMILTON MEDICAL proximal Flow Sensor, between the Y-piece and the patient, and on FiO₂ measurements by the integral oxygen monitor.

Alarms. The HAMILTON-C2's operator-adjustable and non-adjustable alarms help ensure your patient's safety.

User interface. The ventilator's ergonomic design, including a 10.4 in. color touchscreen, a press-and-turn knob, and keys, lets you easily access the ventilator settings and monitored parameters. You can tilt the graphical user interface up to 45°.

Customizability. You can customize the HAMILTON-C2 so that it starts up with institution-defined settings. Per patient group three settings can be predefined.

Power. The HAMILTON-C2 uses as its primary power source AC mains (100 to 240 V AC, 50/60 Hz) or a DC supply (+12 to +24 V). If the primary power source fails, the ventilator power source automatically switches to backup batteries. The standard battery (battery 1) powers the HAMILTON-C2 typically for 3 h, and the optional, hot-swappable battery (battery 2) increases the running time up to 6.5 h.

Mounting variations for the HAMILTON-C2 include a standard trolley, a compact transport solution, and a shelf mount. The trolley has space for oxygen cylinders. With adapter plate for the HAMILTON-C2, the device can be locked up to standard transport trolley.

Nebulization function. The nebulization function lets your HAMILTON-C2 power a pneumatic nebulizer connected to the nebulizer outlet.

The **communications interface** provides an RS-232 port for connection to a remote monitor, patient data management system (PDMS), or other computer system.

The **CO2 sensor** continuously monitors airway carbon dioxide and reports etCO2 and inhaled/exhaled CO₂ for display and alarm purposes.

TRC. Tube resistance compensation

Neonatal ventilation. Ventilation of infant and neonates from a tidal volume of 2 ml.

Options¹.

The following options are available for your HAMILTON-C2:

- **nCPAP-PS.** Is designed to apply nasal continuous positive airway pressure with additional pressure support to infants and neonates.
- **CO2 and nurse call interface.** Gives the possibility to connect CO2 and nurse call on the HAMILTON-C2.

1.2 Functional description

The following paragraphs describe the operation of the HAMILTON-C2 ventilator from a hardware perspective.

1.2.1 System overview

The HAMILTON-C2 is an electronically controlled pneumatic ventilation system with an integrated air compressing system. It is powered by AC or DC with battery backup to protect against power failure or unstable power and to facilitate intra-hospital transport. The HAMILTON-C2's pneumatics deliver gas, and its electrical systems control pneumatics, monitor alarms, and distribute power.

The user provides inputs to the HAMILTON-C2 microprocessor system through a touchscreen, keys, and a press-and-turn knob. These inputs become instructions for the HAMILTON-C2's pneumatics to deliver a precisely controlled gas mixture to the patient. The HAMILTON-C2 receives inputs from the proximal Flow Sensor and other sensors within the ventilator. Based on this monitored data, the HAMILTON-C2 adjusts gas delivery to the patient. Monitored data is also displayed by the graphic user interface.

1. Not all options are available in all markets

The HAMILTON-C2's microprocessor system controls gas delivery and monitors the patient. The gas delivery and monitoring functions are cross-checked by an alarm controller. This cross-checking helps prevent simultaneous failure of these two main functions and minimizes the possible hazards of software failure.

A comprehensive system of visual and audible alarms helps ensure the patient's safety. Clinical alarms can indicate an abnormal physiological condition. Technical alarms, triggered by the ventilator's self-tests, including ongoing background checks, can indicate a hardware or software failure. In the case of some technical alarms, a special safety mode ensures a basic minute ventilation while giving the user time for corrective actions. When a condition is critical enough to possibly compromise safe ventilation, the HAMILTON-C2 is placed into the ambient state. The ambient and expiratory valves are opened, letting the patient inspire room air through the ambient valve and exhale through the expiratory valve.

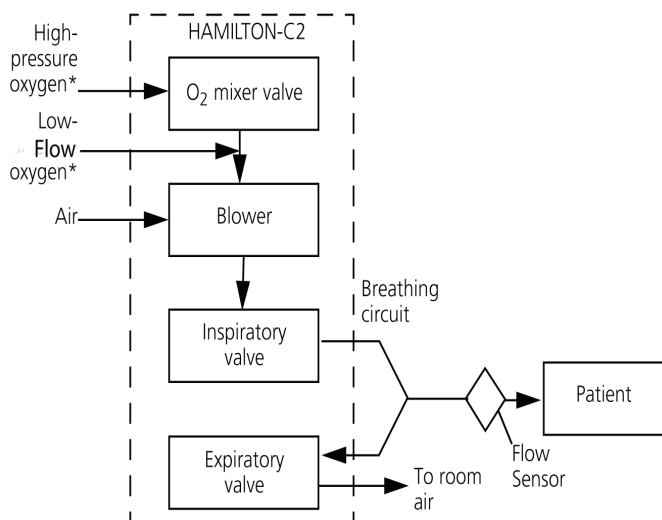
The HAMILTON-C2 has several means to ensure that safe patient or respiratory pressures are maintained. The maximum working pressure is ensured by the high pressure alarm limit. If the set high pressure limit is reached, the ventilator cycles into exhalation. The ventilator pressure cannot exceed 60 cmH₂O.

1.2.2 Gas supply and delivery

The HAMILTON-C2 uses room air and low- or high-pressure oxygen (Figure 1-1). Air enters through a fresh gas intake port and is compressed together with the oxygen by the blower. Oxygen enters through a high¹- or low-pressure² inlet.

1. High pressure oxygen: Maximal Pressure 600kPa / Maximal Flow 120l/min

2. Low Pressure oxygen: Maximal Pressure 600kPa / Maximal Flow 15 l/min



*Only one oxygen source, high- or low-pressure, is required.

Figure 1-1. Gas delivery in the HAMILTON-C2

Within the ventilator, the gas enters the HAMILTON-C2's pneumatic system. If high-pressure oxygen is supplied, a mixer valve provides for the operator-set concentration. If low-pressure oxygen is supplied, the delivered oxygen concentration is determined by the flow of the source oxygen.

Gas is supplied to the patient via the inspiratory valve. The microprocessor controls the size of the inspiratory valve opening and the length of time it is open to meet the user settings.

The HAMILTON-C2 delivers gas to the patient through the inspiratory limb breathing circuit parts, which may include an inspiratory filter, flex tubes, the humidification system, water traps, the Y-piece, and the Flow Sensor. An internal pneumatic nebulizer supplies the nebulizer flow.

Gas exhaled by the patient passes through the expiratory limb breathing circuit parts, including flex tubes, the Flow Sensor, the Y-piece, a water trap, and an expiratory valve cover and membrane. Gas is vented through the expiratory valve cover such that no exhaled gas comes into contact with any internal components of the HAMILTON-C2. Measurements taken at the Flow Sensor are used in the pressure, flow, and volume measurements.

An oxygen cell (sensor) monitors the oxygen concentration of the gas to be delivered to the patient. This galvanic cell generates a voltage proportional to the partial pressure of oxygen in the delivered gas. This oxygen measurement is compensated for changes in pressure.

The operations of the inspiratory and expiratory valves are coordinated to maintain system pressure levels.

1.2.3 Gas monitoring with the Flow Sensor

The HAMILTON-C2 accurately measures flow, volume, and pressure in the patient's airway with the HAMILTON MEDICAL Flow Sensor. This proximal Flow Sensor lets the HAMILTON-C2 sense even weak patient breathing efforts. Between its highly sensitive flow trigger and fast response time, the HAMILTON-C2 helps minimize the patient's work of breathing.

The Flow Sensor contains a thin, diamond-shaped membrane within the outer housing and has a pressure port on either side. The membrane allows bidirectional flow through its variable orifice (Figure 1-2).



Figure 1-2. Flow Sensor

The area of the orifice changes depending on the flow rate. It opens progressively as the flow increases, creating a pressure drop across the orifice. The pressure difference is measured by a high-precision differential pressure sensor inside the ventilator. The pressure difference varies with flow (relationship determined during Flow Sensor calibration), so the patient's flow is determined from the pressure drop. The HAMILTON-C2 calculates volume from the flow measurements.

The Flow Sensor is highly accurate even in the presence of secretions, moisture, and nebulized medications. The HAMILTON-C2 continuously flushes the sensing tubes with mixed gases (rinse flow) to prevent blockage.

1.3 Physical description

1.3.1 Breathing circuits and accessories

NOTE:

To ensure proper ventilation operation, use only parts and accessories specified in Table 1-1.

Figure 1-3 shows the HAMILTON-C2 with its breathing circuit and accessories. Contact your HAMILTON MEDICAL representative for details on breathing circuits and accessories supplied by HAMILTON MEDICAL. See Table 1-1 for information on other compatible breathing circuits and accessories.

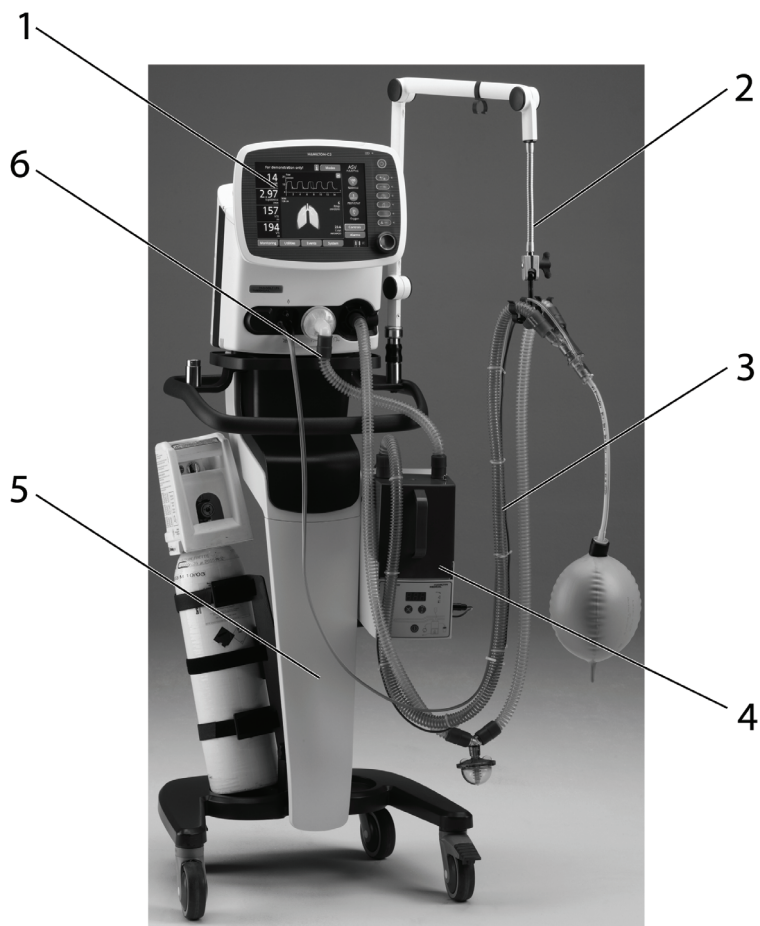


Figure 1-3. HAMILTON-C2 with accessories

- 1 Graphic user interface (GUI)
- 2 Support arm
- 3 Breathing circuit
- 4 HAMILTON-HC humidifier
- 5 Trolley
- 6 Breathing circuit connections

Table 1-1. Compatible parts and accessories

Part	Use...
Patient breathing circuit	• HAMILTON MEDICAL patient breathing circuits • Other circuits that meet the ventilator breathing system specifications in Appendix A.
Mask	• HAMILTON MEDICAL reusable face masks • Other face or nasal masks, except those incorporating an expiratory valve.
Inspiratory filter	• HAMILTON MEDICAL inspiratory bacteria filter • Other filters that have a 22 mm female conical inlet connector and a 22 mm male conical outlet connector, and that meet the ventilator breathing system specifications in Appendix A.
Humidification device	• HAMILTON-HC (HC 180 or HC 200) • Any active humidifier with a flow capability of up to 120 l/min that is approved for the intended use. Humidifiers must comply with EN ISO 9360-1. • Heat and moisture exchanger (HME). HMEs must comply with EN ISO 9360-1.
Flow Sensor	HAMILTON MEDICAL parts only (marked with the HAMILTON "H")
Expiratory valve membrane and cover	HAMILTON MEDICAL parts only
Nebulizer	• Internal nebulizer: Pneumatic nebulizer specified for 8 l/min • External nebulizer: Pneumatic (small-volume) nebulizer powered by an external gas source, or a standalone ultrasonic or electronic (piezo) micropump nebulizer such as the Aerogen® Aeroneb® Pro nebulizer system
Oxygen cell	HAMILTON MEDICAL parts only
Battery	HAMILTON MEDICAL parts only

Table 1-1. Compatible parts and accessories

Part	Use...
CO2 sensor (Mainstream)	HAMILTON MEDICAL CAPNOSTAT 5 TM sensor
CO2 airway adapter (Mainstream)	• HAMILTON MEDICAL CO2 airway adapter • Philips Respironics CAPNOSTAT 5 airway adapter
CO2 sensor (Sidestream)	HAMILTON MEDICAL LoFlow TM sensor
CO2 airway adapter (Sidestream)	• HAMILTON MEDICAL sidestream CO2 airway adapter • Philips Respironics LoFlow airway adapter

1.3.2 Ventilator unit

Figure 1-4 through Figure 1-6 show the controls, indicators, and other important parts of the ventilator unit.

When a key is pressed and the selected function is active, the LED beside the key is lit.



Figure 1-4. Front view

Item	Description
1	Touchscreen
2	Alarm lamp. Entire lamp lights when an alarm is active (red = high-priority alarm, yellow = medium- or low-priority alarm). In addition, a red LED in the middle is continuously lit when alarm silence is active. This red LED flashes when an alarm silence is inactive but an alarm is active.
3 	Battery charge indicator. Lights to show that the batteries can be charged. It is lit whenever the ventilator is connected to AC power or to > 20 V DC, whether or not power is switched on.
4 	Power/standby switch. Powers the ventilator on and off and accesses standby. To put the ventilator into standby, press and quickly release the switch, then select Activate Standby (For details on standby, see Section 9.1). To switch off ventilator power, press the switch quickly to access standby, then press the switch again for > 3 s; or, if there is a technical fault, press and hold the switch for > 10 s.
5 	Screen lock/unlock key. Prevents inadvertent touchscreen entries.
6 	O₂enrichment key. Infant/Neonatal option: Delivers 125% of the last oxygen setting for 2 min. The backlit color changes to green and the currently applied oxygen concentration is displayed on the oxygen knob (green). Pushing the key a second time or manually changing the oxygen concentration (FiO ₂) ends the oxygen enrichment period. Adults and Pediatric: Delivers 100% oxygen for 2 min. The back-lighting changes color to green and the actually applied oxygen concentration is displayed on the oxygen control (green). Pushing the key a second time or manually changing the oxygen concentration (FiO ₂) ends the 100% oxygen enrichment period.
7 	Manual breath/inspiratory hold key. Triggers a mandatory breath when pressed and released during exhalation. Triggers an inspiratory hold when held down during any breath phase. For details see Section 9.3.

Item	Description
8 	Nebulizer on/off key. Activates pneumatic nebulizer, during the inspiration phase if high-pressure oxygen is connected. The indicator is lit whenever nebulization is active. Nebulization stops automatically after 30 min. You can switch it off earlier by pressing the key again. For details, see Section 9.4.
9 	Print screen key. Saves a JPG file of the used ventilator screen to a USB memory key.
10 	Alarm silence key. Silences the main ventilator audible alarm for 2 min. Pushing a second time cancels the alarm silence. The red LED beside the key flashes when an alarm is active but not muted. It is continuously lit while the alarm silence is active.
11	Press-and-turn (P&T) knob. Selects and adjusts ventilator settings and selects monitored data. A green ring around the knob is lit when power is switched on.
12	Expiratory valve cover and membrane
13 	From patient port. The expiratory limb of the patient breathing circuit and the expiratory valve are connected here.
14 	To patient port. The inspiratory filter and the inspiratory limb of the patient breathing circuit are connected here.
15 	Flow sensor connection. Always attach the blue tube to the blue connector and the clear tube to the silver connector.
16 	Pneumatic nebulizer output connector
17	Oxygen cell with cover

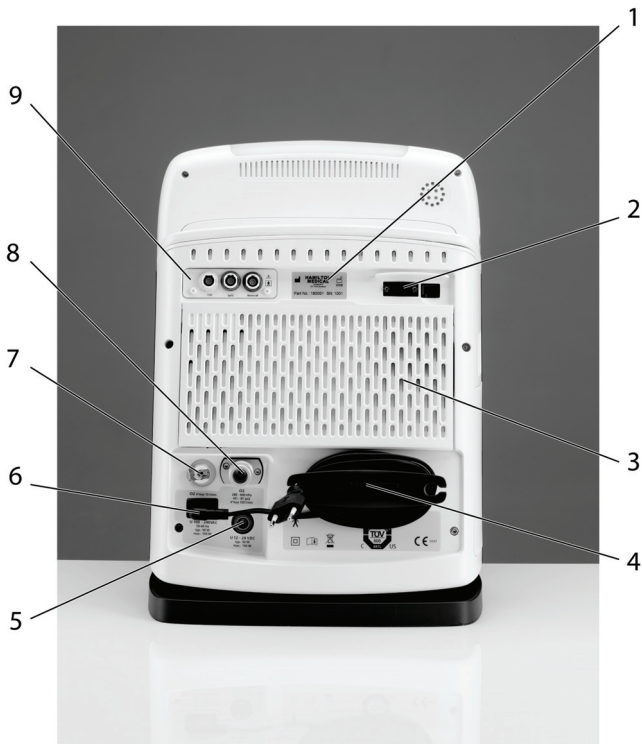


Figure 1-5. Rear view

Item	Description
1	Serial number label
2	RS-232 connector
3	Fresh air intake and cooling fan vents
4	AC power cord with retaining clip
5	DC power connector
6	AC power receptacle

Item	Description
7	Low-flow oxygen connector
8	High-pressure oxygen DISS or NIST inlet fitting
9	Option slot

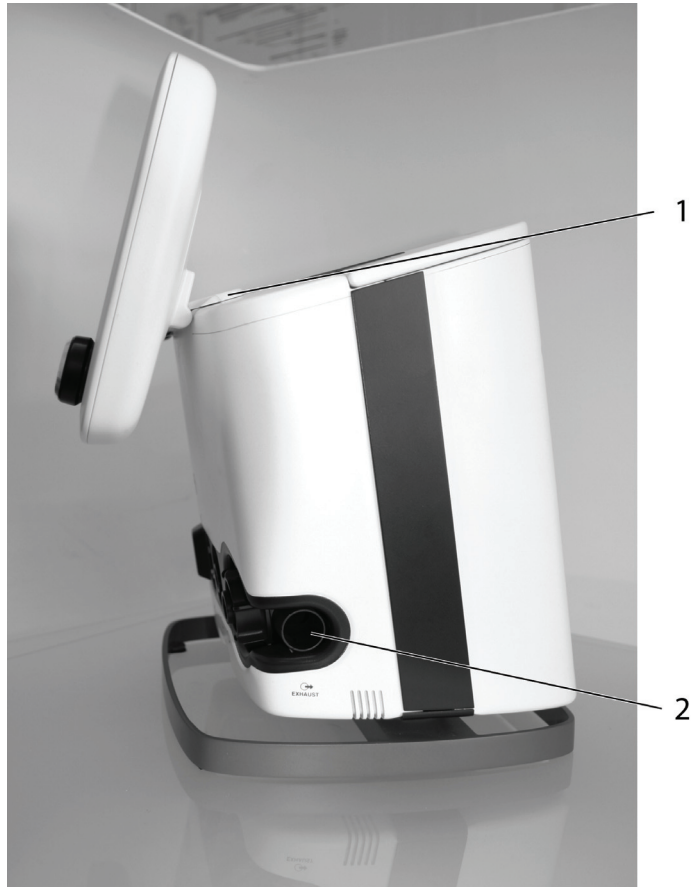


Figure 1-6. Left side view

Item	Description
1	Graphical user interface tilt assembly
2	Expiratory valve cover exhaust port



Figure 1-7. Right side view

Item	Description
1 	USB connector. For software update, event log, and configuration setting export and import. NOTE: The USB connector is intended for passive memory devices only.
2	Battery door

1.3.3 Screen

Directly access all the windows for mode, controls, alarms, and monitoring from the screen during normal ventilation. The default screen is shown (Figure 1-8).

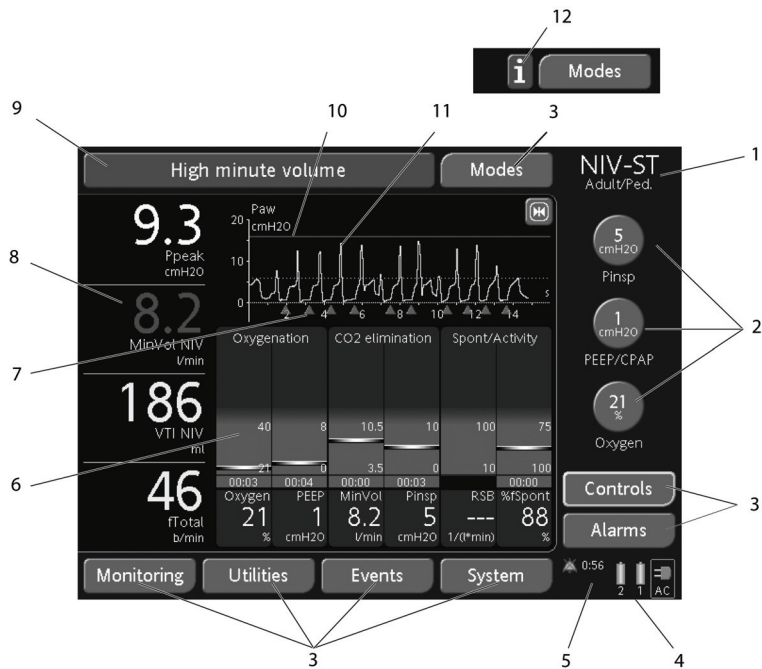


Figure 1-8. Default (basic) screen

Item	Description
1	Active mode and patient group.
2	Main controls. The most important controls. Open the Controls window via the Controls button to show all ventilator controls.
3	Window buttons (tabs). Open the associated windows.

Item	Description
4	Input power. Shows all available power sources. The framed symbol indicates the current source (AC = mains, DC = DC power supply, 1 = battery 1, 2 = battery 2 (optional)). The green part of each battery symbol shows the level of battery charge, while the red shows the level of discharge.
5	Alarm silence countdown. Shows if alarm silence has been activated. Displays the remaining silence time.
6	Graphic display. Shows the pressure/time waveform (curve) plus one additional user-selected graphic, including another real-time waveform or an Intelligent Panel.
7	Trigger symbol. Indicates the patient is triggering a breath.
8	Main monitoring parameters (MMP). You can view other numeric parameters from the monitored parameter windows. If the patient's condition becomes critical, the colour of the numeric parameters change to red and a high priority alarm appears and to yellow for a medium priority alarm.
9	Message bar. Displays alarm messages. If an alarm is active, view the alarm buffer by touching the message bar. See Section 8 for further information.
10	Maximum Pressure Indication Line
11	Pressure limitation. Maximum Pressure - 10 cmH ₂ O.
12	Inactive alarm indicator. Indicates that there is information about inactive alarms in the alarm buffer. View the alarm buffer by touching the inactive alarm indicator.

1.4 Symbols used on device labels and packaging

Table 1-2. Symbols used on device labels and packaging

Symbol	Definition
	Power on/off switch
	Manufacturer
	Date of manufacture
	Type B applied part (classification of medical electrical equipment, type B, as specified by IEC 60601-1)
	Type BF applied part (classification of medical electrical equipment, type BF, as specified by IEC 60601-1)
	Consult operator's manual. Refer to the operator's manual for complete information. This label on the device points the user to the operator's manual for complete information. In the operator's manual, this symbol cross-references the label.

Table 1-2. Symbols used on device labels and packaging (continued)

Symbol	Definition
	CE Marking of Conformity, seal of approval guaranteeing that the device is in conformance with the Council Directive 93/42/EEC concerning medical devices
	Indicates the degree of protection against electric shock according to IEC 60601-1. Class II devices have double or reinforced insulation, as they have no provision for protective grounding.
	"The TÜV NRTL mark with the indicators "C" and "US" means that the product complies with Canadian requirements and the requirements of US authorities for safety."
	Dispose according to Council Directive 2002/96/EC or WEEE (Waste Electrical and Electronic Equipment)
	Serial number
	This way up at transport and storage
	Fragile, handle with care at transport and storage

Table 1-2. Symbols used on device labels and packaging (continued)

Symbol	Definition
	Keep dry at transport and storage
	Temperature limitations at transport and storage
	Humidity limitations at transport and storage
	Atmospheric pressure limitations at transport and storage
	Stacking limitations at transport and storage
	Recyclable materials
	Read the operator's manual

2 Preparing for ventilation

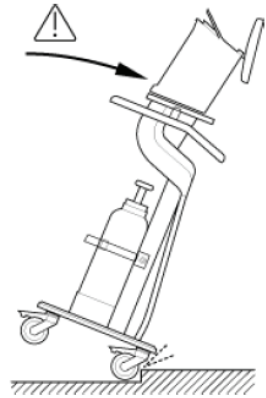
2.1	Introduction	2-2
2.2	Installing the patient tubing support arm	2-4
2.3	Installing the humidifier	2-5
2.4	Installing the option board	2-5
2.5	Installing the patient breathing circuit	2-6
2.6	Installing the pneumatic nebulizer	2-17
2.7	Setting up for monitoring by the optional CO2 sensor	2-19
	2.7.1 CO2 mainstream measurement	2-20
	2.7.2 CO2 sidestream measurement	2-24
2.8	Installing the optional AERONEB Pro nebulizer	2-26
2.9	Using an expiratory filter	2-26
2.10	Connecting to primary power source	2-27
	2.10.1 Connecting to AC power	2-28
	2.10.2 Connecting to DC power	2-28
2.11	About the batteries	2-30
2.12	Connecting the oxygen supply	2-32
2.13	Connecting to an external patient monitor or other device	2-33
2.14	Starting up the ventilator	2-34
2.15	Shutting down the ventilator	2-35
2.16	Display navigation guidelines	2-35

2.1 Introduction

WARNING

- **Additional equipment connected to medical electrical equipment must comply with the respective IEC or ISO standards. Furthermore, all configurations shall comply with the requirements for medical electrical systems (see IEC 60601-1-1 or clause 16 of edition 3 of IEC 60601-1, respectively). Anybody connecting additional equipment to medical electrical equipment configures a medical system and is therefore responsible that the system complies with the requirements for medical electrical systems. Also be aware that local laws take priority over the above mentioned requirements. If in doubt, consult your local representative or Technical Support.**
- **To prevent possible patient injury, do not block the holes at the back of the ventilator. These holes are vents for the fresh air intake and the cooling fan.**
- **To prevent back pressure and possible patient injury, do not attach a spirometer, tube, or other device to the exhaust port of the exhalation valve housing.**
- **To prevent interrupted operation of the ventilator or any accessories, use only accessories or cables that are expressly stated in this manual.**
- **To prevent interrupted operation of the ventilator due to electromagnetic interference, avoid using it adjacent to or stacking other devices on it. If adjacent or stacked use is necessary, verify the ventilator's normal operation in the configuration in which it will be used.**

-
- To prevent possible personal injury and equipment damage, make sure the ventilator is secured to the trolley or shelf with the quick-locking mechanism.
 - To prevent possible equipment damage, avoid tipping over the ventilator when crossing thresholds.
 - To prevent possible equipment damage, lock the trolley's wheels when parking the ventilator.



CAUTION

- Before using the ventilator for the first time, HAMILTON MEDICAL recommends that you clean its exterior and sterilize its components as described in Section 10.
 - To electrically isolate the ventilator circuits from all poles of the supply mains simultaneously, disconnect the mains plug.
-

2.2 Installing the patient tubing support arm

WARNING

To prevent possible patient injury due to accidental extubation, check the support arm joints and secure as necessary.

Install the patient tubing support arm on either side of the HAMILTON-C2 trolley. The arm snaps into place.

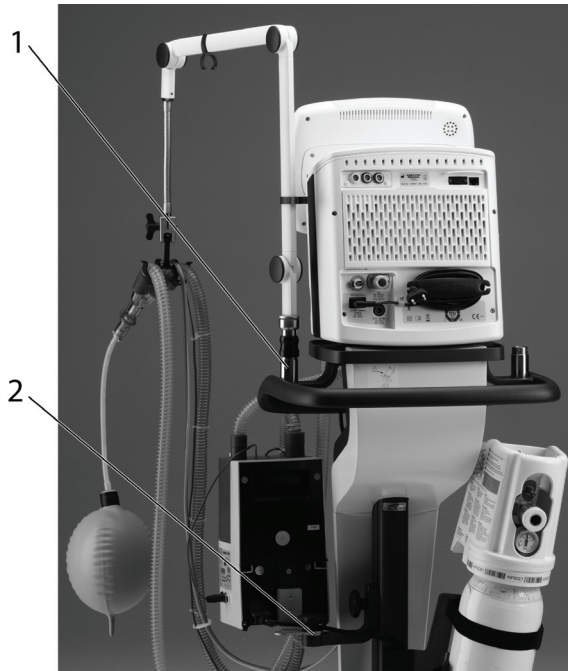


Figure 2-1. Installing the patient tubing support arm and humidifier

- 1 Support arm mount
- 2 Humidifier slide bracket

2.3 Installing the humidifier

WARNING

- To prevent possible patient injury and possible water damage to the ventilator, make sure the humidifier is set to appropriate temperature and humidification settings.
 - To prevent possible patient injury and equipment damage, do not turn the humidifier on until the gas flow has started and is regulated. Starting the heater or leaving it on without gas flow for prolonged periods may result in heat build-up, causing a bolus of hot air to be delivered to the patient. Circuit tubing may melt under these conditions. Turn the heater power switch off before stopping gas flow.
-

Install a humidifier to the HAMILTON-C2 using the slide bracket on the trolley column. Prepare the humidifier as described in the manufacturer's operation manual.

2.4 Installing the option board

C02

Install the option board as follows:

1. Remove the cover of the option slot.
2. Insert the option board containing the interfaces and fix it with the screws.

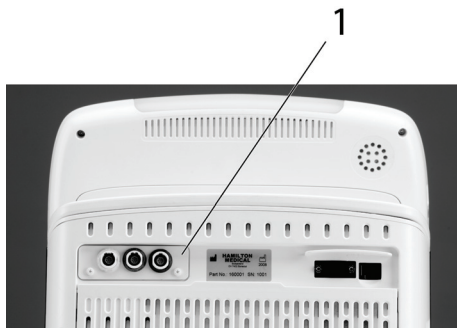


Figure 2-2. Option board

2.5 Installing the patient breathing circuit

WARNING

- To minimize the risk of bacterial contamination or physical damage, handle bacteria filters with care.
 - To prevent patient or ventilator contamination, always use a bacteria filter between the ventilator and the inspiratory limb of the patient breathing circuit.
 - To reduce the risk of fire, use only breathing circuits intended for use in oxygen-enriched environments. Do not use antistatic or electrically conductive tubing.
-

NOTE:

- For optimal ventilator operation, use HAMILTON MEDICAL breathing circuits or other circuits that meet the specifications given in Appendix A. When altering the HAMILTON MEDICAL breathing circuit configurations (for example, when adding accessories or components), make sure not to exceed these inspiratory and expiratory resistance values of the ventilator breathing system, as required by IEC 60601-2-12: neonates, 6 cmH₂O at 30 l/min.
 - Any bacteria filter, HME, or additional accessories in the expiratory limb may substantially increase flow resistance and impair ventilation.
 - To ensure that all breathing circuit connections are leak-tight, perform the tightness test every time you install a circuit or change a circuit part.
 - Regularly check the water traps and the breathing circuit hoses for water accumulation. Empty as required.
 - Do not combine the neonatal CO₂ airway adapter and the Adult Flow sensor. Artefacts during the measurement are possible.
-

1. Install the breathing circuit as follows:
 1. Select the correct breathing circuit parts for your patient from Table 2-1 and Table 2-2.

Table 2-1. Breathing circuit parts according to patient height or IBW

Patient height (cm)	IBW (kg)	Trach tube ID (mm)	Breathing circuit tube ID (mm)	Flow Sensor
30 to 150 (11 to 59 in.)	3 to 48	3 to 7	15	Pediatric/ adult
> 130 (51 in.)	> 30	≥ 5	22	
--	0.2 to 3	≤ 5	10	infant/ neonatal
--	3 to 30	3 to 7	15	

Table 2-2. Tracheal tubes and CO₂

Trach tube ID (mm)	CO ₂ airway adapter
< 4	Neonatal/pediatric (sidestream)
≥ 4	Pediatric/adult (mainstream)

CO₂

2. Assemble the patient breathing circuit. Figure 2-3 through Figure 2-7 show six typical circuit configurations; for ordering information, contact your HAMILTON MEDICAL representative. Follow the specific guidelines for the different parts.
3. Properly position the breathing circuit after assembly. Make sure the hoses will not be pushed, pulled, or kinked during patient's movement, nebulization, or other procedures.

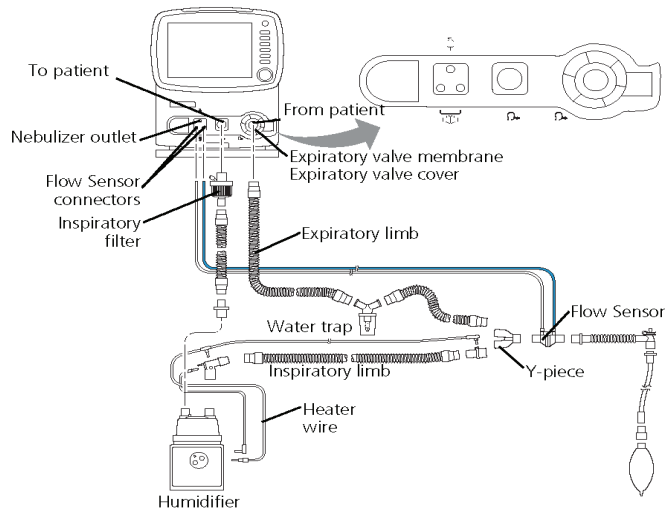


Figure 2-3. Patient breathing circuit for use with inspiratory heater wire (Pediatric/Adult) - (In place of the flex tube shown, a 15 x 22 adapter may be used to attach the Flow Sensor to the ET tube.)

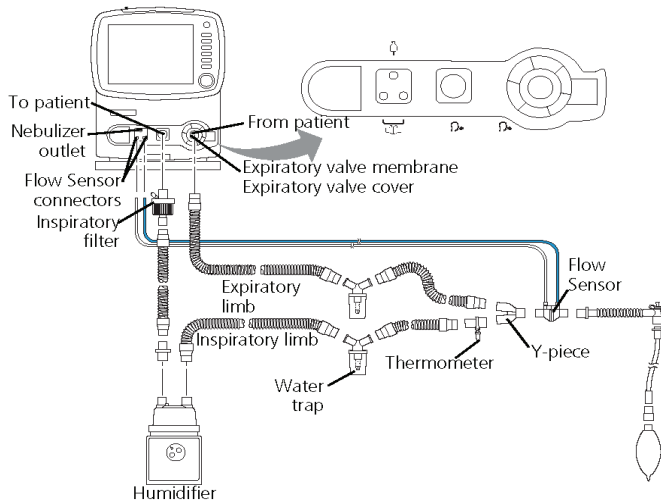


Figure 2-4. Patient breathing circuit for use without heater wires (Pediatric/Adult) - (In place of the flex tube shown, a 15 x 22 adapter may be used to attach the Flow Sensor to the ET tube.)

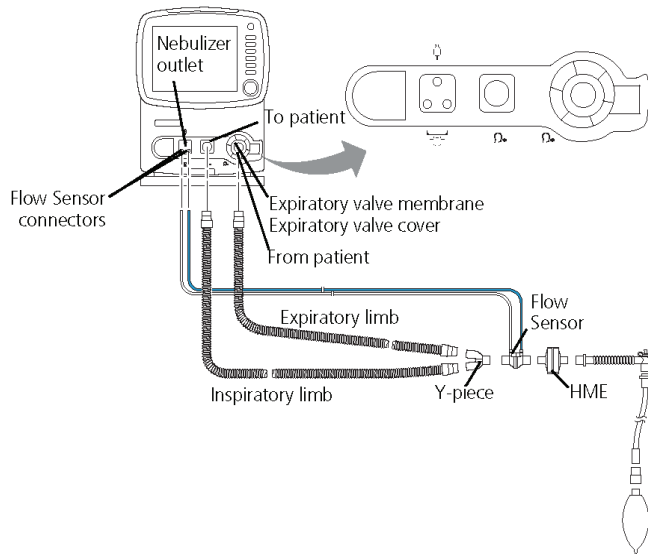


Figure 2-5. Patient breathing circuit for use with HME (Pediatric/Adult) -

(In place of the flex tube shown, a 15 x 22 adapter may be used to attach the Flow Sensor to the HME or ET tube.)

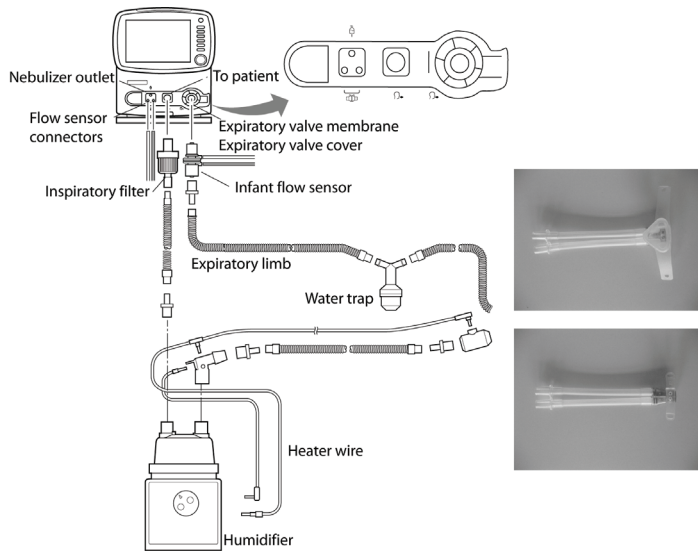


Figure 2-6. Patient breathing circuit with inspiratory heater wire for use with nCPAP-PS (non-invasive ventilation neonatal) - (Use a 15M x 15F adapter to connect the infant flow sensor.)

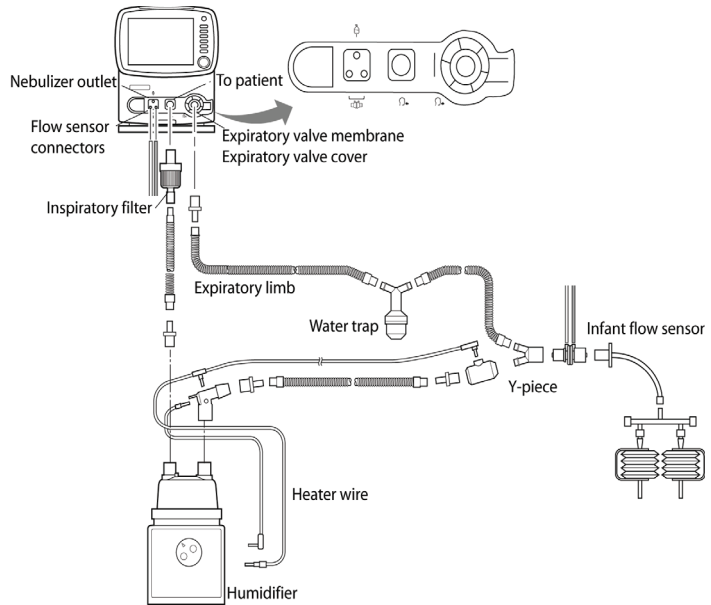


Figure 2-7. Patient breathing circuit with inspiratory heater wire (invasive ventilation neonatal) - (Use a 15M x 15F adapter to connect the infant flow sensor.)

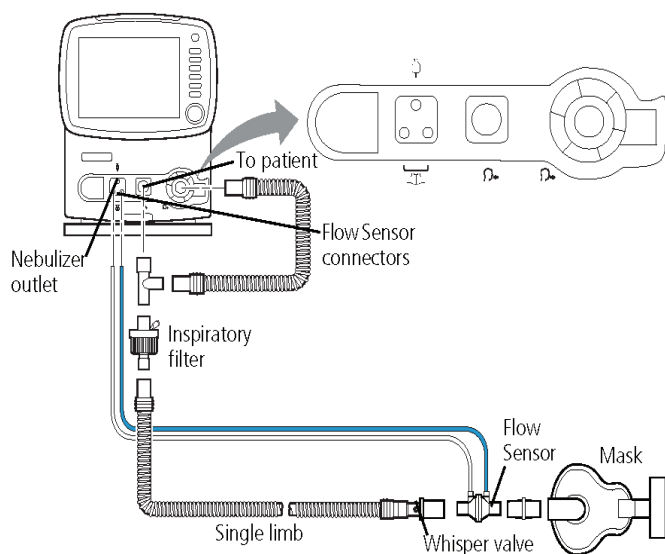


Figure 2-8. LiteCircuit (single-limb) patient breathing circuit (non-invasive ventilation Pediatric/Adult) - (For use with NIV or NIV-ST)

Expiratory valve membrane: Holding the expiratory valve housing (Figure 2-9) upside-down, seat the silicone membrane onto the housing. The metal plate goes toward the ventilator. Position the housing and twist clockwise until it locks into place.

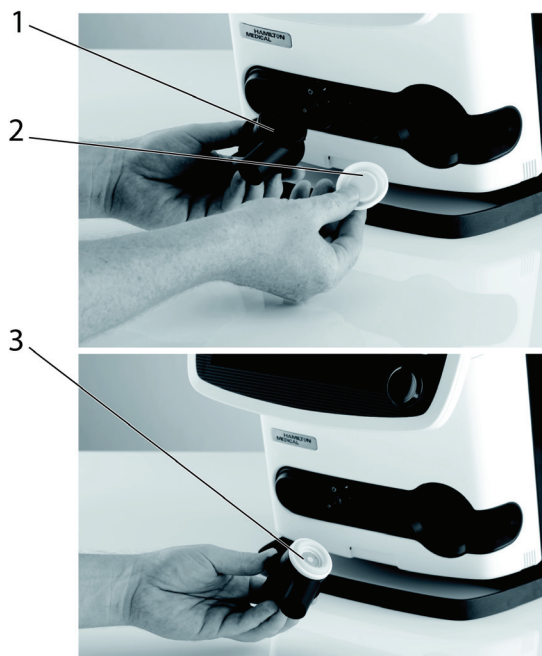


Figure 2-9. Installing the expiratory valve

- 1** Expiratory valve housing
- 2** Expiratory valve membrane
- 3** Metal plate toward ventilator

Flow sensor: Insert a Flow Sensor between the Y-piece of the breathing circuit and the patient connection (Figure 2-10). Connect the blue and colorless tubes to the Flow Sensor connectors in the front panel. The blue tube goes to the blue connector. The colorless tube goes to the silver connector.

NOTE:

To prevent inaccurate Flow Sensor readings, make sure the Flow Sensor is correctly installed:

- The Flow Sensor tubings must not be kinked.
 - The Flow Sensor tubings must be secured with clamp (included with Flow Sensor).
 - In the nCPAP-PS mode the correct position of the flow sensor is at the expiratory valve.
-



Figure 2-10. Installing the Flow Sensor

2.6 Installing the pneumatic nebulizer

WARNING

- **Do not use an expiratory filter or HME in the patient's breathing circuit during nebulization. Nebulization can cause an expiratory side filter to clog, substantially increasing flow resistance and impairing ventilation.**
 - **Connect the nebulizer in the inspiratory limb per your institution's policy and procedures. Connecting the nebulizer between the Flow Sensor and the endotracheal tube increases dead space ventilation.**
 - **To prevent the expiratory valve from sticking due to nebulized medications, use only medications approved for nebulization and regularly check and clean or replace the expiratory valve membrane.**
 - **Be aware that nebulization affects delivered oxygen concentration.**
-

NOTE:

- To change the nebulizer settings open the configuration mode.
 - Nebulization is disabled during the neonatal application.
-

The nebulization feature provides a stable driving pressure to power a pneumatic nebulizer connected to the nebulizer outlet, optimally specified for 6 to 7 l/min flow.

Connect the nebulizer and accessories as shown in Figure 2-11. Table 1-1 has information about compatible nebulizers.

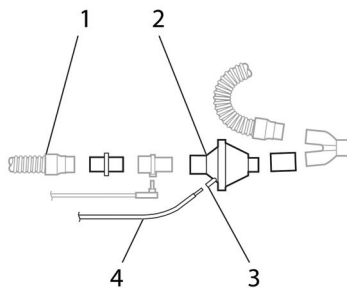


Figure 2-11. Installing a pneumatic nebulizer

- 1** Inspiratory limb
- 2** Nebulizer
- 3** Connector
- 4** Tube

2.7 Setting up for monitoring by the optional CO₂ sensor

CO₂

WARNING

- Always ensure the integrity of the patient breathing circuit after insertion of the airway adapter by verifying a proper CO₂ waveform (capnogram) on the ventilator display.
 - If the capnogram appears abnormal, inspect the CO₂ airway adapter and replace if needed.
 - Monitor the capnogram for higher-than-expected CO₂ levels during ventilation. These can be caused by sensor or patient problems.
 - Use the correct adapter. In adult patients small geometrics may induce low tidal volumes and intrinsic PEEP. In neonatal patients large geometrics detain effective CO₂ removal.
 - Do not use the CO₂ sensor if it appears to have been damaged or if it fails to operate properly. Refer servicing to HAMILTON MEDICAL authorized personnel.
 - To reduce the risk of explosion, do not place the CO₂ sensor in a combustible or explosive environment (for example, around flammable anesthetics or other ignition sources).
 - Do not operate the CO₂ sensor when it is wet or has exterior condensation.
 - Avoid permanent direct contact of the CO₂ sensor with the body.
 - Nebulization may influence the CO₂ measurements.
-

CAUTION

- **Position airway adapters with windows in a vertical, *not* a horizontal, position. This helps keep patient secretions from pooling on the windows.**
 - **To prevent premature failure of the CO₂ sensor, HAMILTON MEDICAL recommends that you remove it from the circuit whenever an aerosolized medication is delivered. This is due to the increased viscosity of the medication, which may contaminate the airway adapter window.**
 - **All devices are not protected against reanimation with a defibrillator.**
 - **Disconnect the CO₂ sensor before using a defibrillator to the patient.**
-

CO₂ monitoring is used for various applications in order to gain information such as the assessment of the patient's airway integrity or the proper endotracheal tube placement. For the HAMILTON-C2 two possibilities to monitor CO₂ are possible:

- mainstream CO₂ measurement
- sidestream CO₂ measurement

Whether, mainstream or sidestream CO₂ is used to monitor end-tidal CO₂ depends on the clinical setting. A volumetric capnogram as described in chapter "Volumetric Capnography" is only possible with a mainstream CO₂ sensor.

2.7.1 CO₂ mainstream measurement

WARNING

In NIV and neonatal ventilation with uncuffed tubes leaks may influence the volumetric capnogram and the deduced numerical monitoring parameters.

2.7.1.1 Introduction

The optional mainstream CO₂ sensor is a solid-state infrared sensor, which is attached to an airway adapter that connects to an endotracheal (ET) tube or other airway and measures bases flowing through these breathing circuit components.

The sensor generates infrared light and beams it through the airway adapter or sample cell to a detector on the opposite side. CO₂ from the patient, flowing through the mainstream airway adapter or aspirated into the sample cell, absorbs some of this infrared energy. The HAMILTON-C2 determines the CO₂ concentration in the breathing gases by measuring the amount of light absorbed by gases flowing through the airway or sample cell.

The HAMILTON-C2 can display measurements derived from the CO₂ sensor as numeric values, waveforms, trends, and loops. The waveform is a valuable clinical tool that can be used to assess patient airway integrity and proper endotracheal (ET) tube placement.

The CO₂ sensor can be easily transferred from one HAMILTON-C2 ventilator to another, even "on the fly", during ventilation.

2.7.1.2 Connecting the CO2 mainstream sensor

Set up the HAMILTON-C2 for CO₂ monitoring, as follows:

1. Plug the sensor cable into the CO₂ module connector (Figure 2-12), observing the orientation of the indexing guides on the connector body. The cable should snap into place.
2. Attach the airway adapter to the CO₂ sensor:
 - A. Verify that the adapter windows are clean and dry. Clean or replace the adapter if necessary.
 - B. Align the arrow on the bottom of the adapter with the arrow on the bottom of the sensor.

Press the sensor and the adapter together until they click (Figure 2-12).

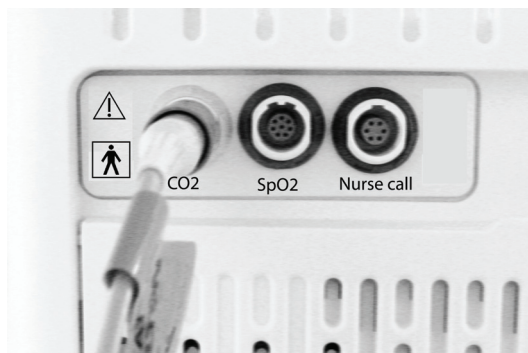


Figure 2-12. Connecting the CO2 sensor

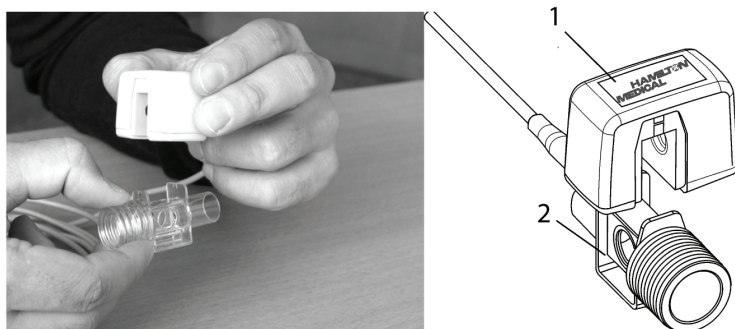


Figure 2-13. Attaching the CO2 sensor to the airway adapter

- 1 CO2 sensor
 - 2 Adapter
3. Connect the sensor/airway adapter to the patient circuit as follows (Figure 2-14):
- A. Place the sensor/airway adapter assembly at the proximal end of the airway circuit as shown. Do *not* place the airway adapter between the ET tube and the elbow, as

this may allow patient secretions to accumulate in the adapter.

- B. Position the airway adapter with its windows in a vertical, not a horizontal, position. This helps keep patient secretions from pooling on the windows. If pooling does occur, the airway adapter may be removed from the circuit, rinsed with water and reinserted into the circuit. To prevent moisture from draining into the airway adapter, do *not* place the airway adapter in a gravity-dependent position.

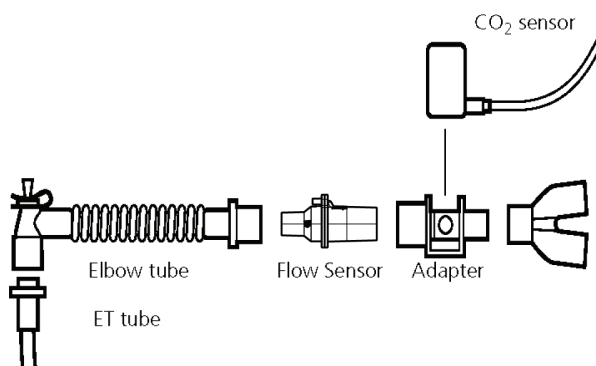


Figure 2-14. Connecting the CO₂ sensor/airway adapter to the patient circuit

4. Check that connections have been made correctly by verifying the presence of a proper CO₂ waveform (capnogram) on the HAMILTON-C2 display. Monitor the capnogram for higher-than-expected CO₂ levels. If CO₂ levels are higher than expected, verify patient condition first. If you determine that the patient's condition is not contributing, calibrate the sensor.
5. The sensor cable should face away from the patient. To secure the sensor cable safely out of the way, attach sensor cable holding clips to the airway tubing, then connect the sensor cable to the clips.

To remove the sensor cable, pull back on the connector sheath and disengage from connector.

2.7.2 CO₂ sidestream measurement

2.7.2.1 Introduction

The optional side stream CO₂ sensor samples gases over sampling port placed into the breathing circuit proximal to the patient. The gas passes through sampling tube to the sample cell. The sampling tube is water permeable in order to minimize cross interference effects and collision broadening. The sampling cell measures the gas components are using infrared spectroscopy at a wavelength of 4260 nm. The measured values can be displayed by the HAMILTON-C2 as real-time waveform, loops, and trends and as numeric values.

2.7.2.2 Connecting the CO₂ sidestream sensor

WARNING

- **Do not use patients that cannot tolerate the removal of 50 ml/min from their total minute ventilation.**
-

Set up the device for CO₂ sidestream monitoring, as follows:

1. Plug the LoFlo™ CO₂ Module cable into the CO₂ option board connector (yellow), observing the orientation of the indexing guides on the connector body. The cable should snap into place.
2. The sample cell of the sampling kit must be inserted into the sample cell receptacle of the LoFlo™ CO₂ Module as shown in the figure below. A “click” will be heard when the sample cell is properly inserted.

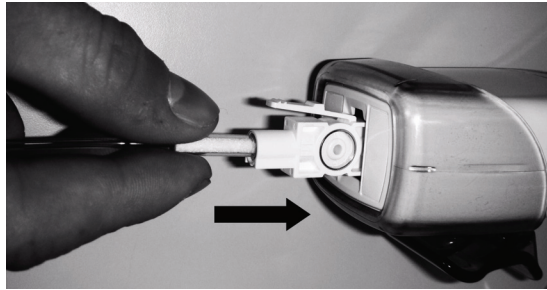


Figure 2-15. Inserting the sample cell into the receptacle

3. Inserting the sample cell into the receptacle automatically starts the sampling pump. Removal of the sample cell turns the sample pump off.
4. Install the airway adapter between Flow Sensor and ET tube.
5. The sample line should face away from the patient. To secure the sample line safely out of the way, attach sensor cable holding clips to the airway tubing, then connect the sample line to the clips.

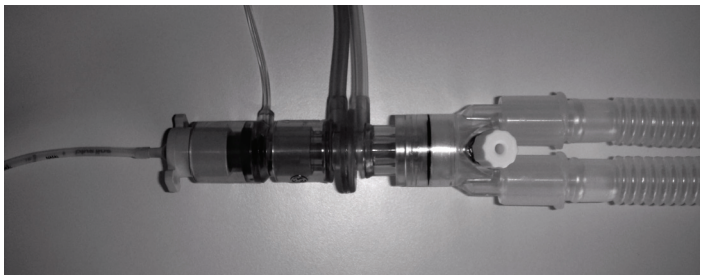


Figure 2-16. Attaching the CO2 sensor to the airway adapter

- 1 CO2 sensor
- 2 Adapter

To remove the sampling kit sample cell from the sample cell receptacle, press down on the locking tab and pull the sample cell from the sample cell receptacle.

2.8 Installing the optional Aeroneb Pro nebulizer

The Aerogen Aeroneb Pro nebulizer system is available as an option for the HAMILTON-C2. Attach it to the mounting bracket. Consult the operating instructions supplied with the nebulizer for further installation and operating information.



Figure 2-17. Installing the Aeroneb Pro nebulizer

2.9 Using an expiratory filter

CAUTION

The use of an expiratory filter may lead to a significant increase in expiratory circuit resistance. Excessive expiratory circuit resistance may compromise ventilation and increased patient work of breathing and/or AutoPEEP.

NOTE:

Monitored parameters for increased expiratory resistance are not specific to the breathing circuit and may indicate increased patient airway resistance and/or increased resistance of the artificial airway (if used). Always check the patient and confirm adequate ventilation.

An expiratory filter is not required on the HAMILTON-C2, but you may use one according to your institution's protocol. An expiratory filter is not required, because the expiratory valve design prevents internal ventilator components from contact with the patient's exhaled gas.

If you do use an expiratory filter, place it on the patient side of the expiratory valve cover. Remove any expiratory filter or HME during nebulization. Monitor closely for increased expiratory circuit resistance. An **Exhalation obstruction** alarm may also indicate excessive expiratory circuit resistance. If the **Exhalation obstruction** alarm occurs repeatedly, remove the expiratory filter immediately. If you otherwise suspect increased expiratory circuit resistance, remove the expiratory filter or install a new filter to eliminate it as a potential cause.

2.10 Connecting to primary power source

Either AC or DC can supply the primary power to the HAMILTON-C2.

2.10.1 Connecting to AC power

NOTE:

- To prevent unintentional disconnection of the power cord, make sure it is well seated into the ventilator socket and secured with the power cord retaining clip.
 - The HAMILTON-C2 does not require protective earth grounding, because it is a class II device, as classified according to IEC 60601-1.
-

Connect the HAMILTON-C2 to an outlet that supplies AC power between 100 and 240 V, 50/60 Hz. Always check the reliability of the AC outlet. The AC power symbol in the bottom right-hand corner of the screen is displayed with a frame around it.

2.10.2 Connecting to DC power

CAUTION

Connect the HAMILTON-C2 to the 12 to 24 V DC on-board power circuit of an ambulance vehicle only!

If the HAMILTON-C2 is connected to a DC power source the DC power symbol in the bottom right-hand corner of the screen is displayed with a frame around it.

2.10.2.1 Car adapter

NOTE:

- Only the HAMILTON car adapter is allowed to be use with the HAMILTON-C2.
 - Connect the HAMILTON car adapter to the DC jack of the HAMILTON-C2.
 - The input power of the car adapter, from 11 to 32 V ensures that the batteries 1+2 of HAMILTON-C2 are charged.
 - The HAMILTON car adapter is intended to be used during secondary transport.
 - The use of the device for secondary transport in aircrafts is not permitted.
-

A car adapter is available in order to connect the HAMILTON-C2 to DC. The car adapter transfers input voltage to 24 V, and allows for charging the batteries.



Figure 2-18. Car adapter

2.11 About the batteries

NOTE:

- The use of one battery is mandatory. The battery is used as internal backup battery.
 - HAMILTON MEDICAL recommends that the ventilator's batteries be fully charged before you ventilate a patient. If the batteries are not fully charged and AC power fails, always pay close attention to the level of battery charge.
-

Two backup batteries, one mandatory and the other optional, protect the HAMILTON-C2 from low, or failure of, the primary power source. When the primary power source (either AC mains or a DC power supply) fails, the ventilator automatically switches to operation on backup battery with no interruption in ventilation. An alarm sounds to signal the switchover. Silence the alarm to confirm notification of the power system change; this resets the alarm. If the optional battery (battery 2) is available and adequately charged, the ventilator switches to this battery first. When battery 2 is depleted or not installed, the ventilator switches to the standard battery (battery 1). The batteries power the ventilator until the primary power source is again adequate or until the battery is depleted. Two batteries power the ventilator typically for 6.5 h.

As a further safeguard, the HAMILTON-C2 provides a low battery alarm. It also has a capacitor-driven backup buzzer that sounds continuously for at least 2 min when battery power is completely lost.

The ventilator charges the batteries whenever the ventilator is connected to either AC or DC > 20 V, with or without the ventilator power switch on. The battery charge indicator lights show that the batteries are being charged.



Figure 2-19. Power source symbols and battery charge indicator

- 1 Battery charge indicator
- 2 Crossed-out battery 1 means standard battery not available
- 3 AC mains symbol (or DC)
- 4 Frame indicates current power source

The power source symbols in the bottom right-hand corner of the screen show the available power sources. A frame around a symbol indicates the current ventilator power source. Green indicates the level of battery charge.

Check the battery charge level before putting the ventilator on a patient and before unplugging the ventilator for transport or other purposes. A green symbol indicates a fully charged battery. A red and green symbol indicates a partially charged battery. If battery symbol 1 is crossed out, the standard battery is discharged or defective. If battery symbol 2 is not shown, the

optional battery is not installed. If a battery is not fully charged, recharge it by connecting the ventilator to the primary power source for a minimum of 4 h, until the battery charge level is 80 to 100%. Alternatively, the battery can also be charged with the external charger.

Section 9.3.2 describes how to replace the batteries.

2.12 Connecting the oxygen supply

CAUTION

- **Always check the status of the oxygen cylinders or other supply before using the ventilator during transport.**
 - **Make sure oxygen cylinders are equipped with pressure-reducing valves.**
 - **To minimize the risk of fire, do not use high-pressure gas hoses that are worn or contaminated with combustible materials like grease or oil.**
-

NOTE:

- To prevent damage to the ventilator, connect only clean, dry medical-grade oxygen.
 - Before starting ventilation, make sure the appropriate oxygen source, either high-pressure oxygen (**HPO mode**) or low-pressure oxygen (**LPO mode**), was selected during configuration, see Appendix J.
-

Oxygen for the HAMILTON-C2 can come from a high- or low-pressure source.

High-pressure oxygen (Flow: ≤ 120 l/min, Pressure: 2.8 to 6 bar/280 to 600 kPa/41 to 87 psi), provided by a central gas supply or a gas cylinder, is supplied through DISS or NIST male gas fittings. With the optional cylinder holder, you can mount oxygen cylinders to the trolley. If you use gases from cylinders, secure the cylinders to the trolley with the accompanying straps.

Low-flow oxygen (Flow: ≤ 15 l/min, Pressure: ≤ 6 bar/600 kPa/87 psi) is provided by a concentrator or liquid cylinder. For information about connecting low-pressure oxygen, see Appendix F.

Connect the oxygen hose to the HAMILTON-C2's high-pressure or low-flow oxygen inlet fitting, shown in Figure 2-20.

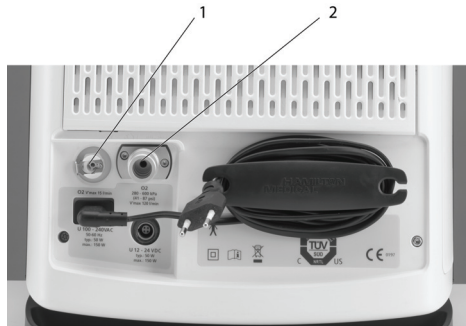


Figure 2-20. Oxygen inlet fittings

- 1 Oxygen low pressure fitting
- 2 Oxygen high-pressure inlet fitting

2.13 Connecting to an external patient monitor or other device

NOTE:

All devices connected to the HAMILTON-C2 must be for medical use and meet the requirements of standard IEC 60601-1.

You can connect your ventilator to a patient monitor, a Patient Data Monitoring System (PDMS), or a computer via the RS-232 port. See Appendix I for details on the communications interface.

2.14 Starting up the ventilator

CAUTION

To ensure the ventilator's safe operation, always run the preoperational check before using the ventilator on a patient. If the ventilator fails any tests, remove it from clinical use immediately. Do not use the ventilator until necessary repairs are completed and all tests have passed.

NOTE:

If the HAMILTON-C2 is new, be sure it has been properly configured for default language, alarms, and others (see Appendix J).

1. Switch on the ventilator power switch. The ventilator will run a self-test.



Figure 2-21. Power switch

- 1 Power switch

2. After a short time, you will see the patient setup window. Set up the ventilator as described in Section 4.2.
3. Run the preoperational check (Section 3.2).

2.15 Shutting down the ventilator

NOTE:

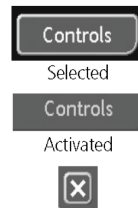
The ventilator remains connected to power when the power switch is switched off. This permits the batteries to charge. To completely disconnect the ventilator from power, unplug it from the mains power outlet or disconnect it from the DC supply.

To shut the HAMILTON-C2 down, press and quickly release the power switch to access standby, then press the switch again for > 3 s; or, if there is a technical fault, press and hold the switch for > 10 s.

2.16 Display navigation guidelines

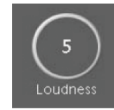
Use the touchscreen and the press-and-turn knob to access the HAMILTON-C2 ventilation parameters and monitored data. You typically use a select - activate or select - activate - adjust - activate procedure.

To open a window, touch the window tab to select and activate it; or turn the knob to select the window tab (it is framed in yellow) and then press the knob to activate your selection.



To close a window, touch the window tab or the X in the upper left-hand corner to select and activate it; or turn the knob to select the X (it is framed in yellow) and then press the knob to activate your selection.

To adjust a control, touch the control to select and activate it; or turn the knob to select the control (it is framed in yellow) and then press the knob to activate your selection. The activated control turns red. Turn the knob to increment or decrement the value. Press the knob or touch the control to confirm the adjustment and deactivate.

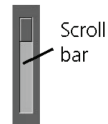


Selected



Activated

To scroll through a log using the scroll bar or arrows, touch the scroll bar to select and activate it; or turn the knob to select the scroll bar (it is framed in yellow) and then press it to activate your selection. Your selection becomes red when activated. Now turn the knob to scroll through the log. Touch the scroll bar or press the knob to deactivate.



3 Tests, calibrations and utilities

3.1	Introduction	3-2
3.2	Running the preoperational check	3-4
3.3	System functions	3-6
3.3.1	Info: Viewing device-specific information	3-6
3.3.2	Tests & calib: Running sensor calibrations and the tightness test	3-7
3.3.3	Sensors on/off: Enabling/disabling O2 and CO2 monitoring	3-15
3.3.4	Setting day and night	3-16
3.3.5	Setting date and time	3-17
3.4	Utilities	3-18
3.4.1	Configuration: Configuring the ventilator	1+18
3.4.2	Data transfer: Copying event log data to a USB memory device	3-19
3.5	Alarm tests	3-21
3.5.1	High pressure	3-21
3.5.2	Low minute volume	3-22
3.5.3	Low oxygen alarm	3-22
3.5.4	Disconnection on patient side	3-22
3.5.5	Loss of external power	3-23
3.5.6	Exhalation obstructed	3-23
3.5.7	Apnea	3-23

3.1 Introduction

The tests and calibrations described in this section help verify the safety and reliability of the HAMILTON-C2. Perform the HAMILTON-C2's tests and calibrations as described in Table 3-1. If a test fails, troubleshoot the ventilator as indicated or have the ventilator serviced. Make sure the tests pass before you return the ventilator to clinical use.

Table 3-1. When to perform tests and calibrations

When to perform	Test or calibration
Before placing a new patient on the ventilator CAUTION To ensure the ventilator's safe operation, always run the full preoperational check before using the ventilator on a patient. If the ventilator fails any tests, remove it from clinical use immediately. Do not use the ventilator until necessary repairs are completed and all tests have passed.	Preoperational check
After installing a new or decontaminated breathing circuit or component (including a Flow Sensor)	Tightness test, Flow Sensor calibration
After installing a new oxygen cell or when a related alarm occurs	Oxygen cell calibration

Table 3-1. When to perform tests and calibrations (continued)

When to perform	Test or calibration
Required after installing a new, previously unused CO₂ sensor or when a related alarm occurs, recommended after switching between different airway adapter types NOTE: All calibration data is saved in the sensor head. Therefore, when a previously used sensor is reconnected, you need not recalibrate the sensor unless you have changed the adapter type.	CO2 sensor/adapter calibration (mainstream/ sidestream)
As desired	Alarm tests

3.2 Running the preoperational check

CAUTION

To prevent possible patient injury, disconnect the patient from the ventilator before running this test. Make sure another source of ventilatory support is available.

When to perform: Before placing a new patient on the ventilator.

Required materials: Use the setup below appropriate to your patient type. To ensure that the ventilator also functions according to specifications on your patient, we recommend that your test circuit be equivalent to the circuit used for ventilation.

Adult patients	- Breathing circuit, 22 mm ID with 22F connectors - Flow Sensor, pediatric/adult - Demonstration lung, 2 l, with adult ET tube between Flow Sensor and lung (PN 281637 or equivalent)
Pediatric patients	- Breathing circuit, 15 mm ID with 22F connectors - Flow Sensor, pediatric/adult - Demonstration lung, 0.5 l, with pediatric ET tube between Flow Sensor and lung (PN 151816 or equivalent)
Neonatal patients	- Breathing circuit, 10 mm ID with 10F connectors - Flow Sensor, infant - Lung model, neonatal, with neonatal ET tube between Flow Sensor and lung model (An Ing-Mar neonatal lung model is recommended)

Procedure:

Do or observe...	Verify...	Notes
1. Connect ventilator to AC or DC power and oxygen supply. Assemble the patient breathing circuit.	Breathing circuit is assembled correctly.	See Figure 2-2 through 2-7.
2. Switch on power.	When ventilator is switched on, buzzer sounds and the red alarm lamp flashes. After the self-test is passed the alarm lamp flashes red again.	The buzzer sounds only briefly in the beginning.
3. Make sure the ventilator is in standby, and select Preop-check from the Patientsetup window.		
4. Open System -> Tests & calib window (Figure 3-2). Select and run the Tightness test, then the Flow Sensor calibration. Follow all prompts.	These tests pass.	For details on running these tests and calibrations, refer to Section 3.3.2.
5. If necessary, run O2 cell calibration . Close window.	These tests pass.	See Section 3.3.2.4.

Do or observe...	Verify...	Notes
6. Generate an alarm (for example, by disconnecting mains power).	Corresponding alarm message in message bar (for example, Loss of external power).	During standby, patient alarms are suppressed.
7. Resolve the alarm situation (for example, reconnect mains power).	Alarm is reset.	

Corrective action: If the ventilator does not pass the preoperational check, have it serviced.

3.3 System functions

NOTE:

The audible alarm is silenced during the calibration functions and for 30 s thereafter.

You can run tests and calibrations, view device-specific information, and perform other ventilator system functions from the **System** window.

3.3.1 Info: Viewing device-specific information

Open the **System -> Info** window to view device-specific information.



Figure 3-1. Info window

3.3.2 Tests & calib: Running sensor calibrations and the tightness test

NOTE:

To enable or disable O2 and CO2 monitoring see chapter 3.3.3.

Open the **System** -> **Tests&calib** window to access the tests and calibrations.

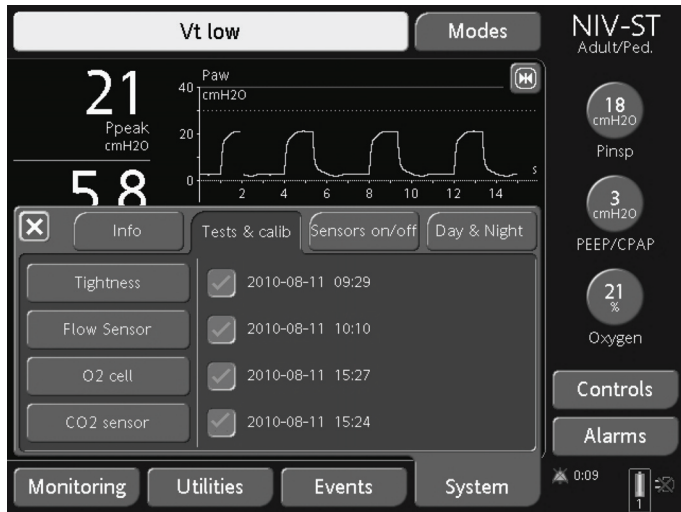


Figure 3-2. Tests & calib window

3.3.2.1 Tightness test

NOTE:

- Make sure another source of ventilatory support is available during this test. The patient must be disconnected from the ventilator during it.
- To cancel the tightness test while it is in progress, select **Tightness** again.

Description: This test checks for leakage in the patient breathing circuit and determines the circuit's compliance compensation factor. The ventilator is pressurized to 50 cmH₂O. The circuit is considered tight if this pressure can be maintained. If there is a leak, the pressure falls in proportion to the size of leak.

Procedure:

1. Set the ventilator up as for normal ventilation, complete with the breathing circuit.
2. Activate **Tightness test** from the **Tests&calib** window.
3. **Disconnect patient** is now displayed. Disconnect the breathing circuit at the patient side of the Flow Sensor. Do not block the open end of the Flow Sensor.
4. **Tighten patient system** is now displayed. Block the opening (a finger covered with an alcohol pad may be used).
5. **Connect patient** is now displayed. Reconnect the patient.
6. VERIFY that there is a green check mark in the box beside **Tightness**.

Corrective action:

Troubleshoot any alarms as described in Section 8.

3.3.2.2 Tightness test with the LiteCircuit

NOTE:

- Make sure another source of ventilatory support is available during this test. The patient must be disconnected from the ventilator during it.
 - To cancel the tightness test while it is in progress, select **Tightness** again.
-

Description: This test checks for leakage in the patient breathing circuit and determines the circuit's compliance compensation factor. The ventilator is pressurized to 50 cmH₂O. The circuit is considered tight if this pressure can be maintained. If there is a leak, the pressure falls in proportion to the size of leak.

Procedure:

1. Set the ventilator up as for normal ventilation, complete with the LiteCircuit.
2. Disconnect the Whisper valve together with Flow Sensor from the circuit.
3. Activate **Tightness test** from the **Tests&calib** window.
4. The message line displays **Patient system**. Block the opening with a clean gauze-covered finger.
5. **Connect patient** is now displayed. Reconnect the Whisper valve with Flow Sensor.
6. Repeat the **Tightness test** as described above (steps 3 to 4).
7. VERIFY that there is a green check mark in the box besides **Tightness**.
8. Reconnect the patient.

3.3.2.3 Flow Sensor calibration

NOTE:

- Make sure another source of ventilatory support is available during this calibration. The patient must be disconnected from the ventilator during it.
- To cancel the Flow Sensor calibration while it is in progress, select **FlowSensor** again.
- Circuit resistance compensation measured during calibration.
- If you are using a LiteCircuit, block the opening of the whisper valve with a clean gauze-covered finger.
- Do not turn the infant Flow Sensor during calibration.
- The flow sensor must be on the correct position. Intending to ventilate with nCPAP-PS, the flow sensor calibration has to be done with the flow sensor at the proximal side of the patient and not at the expiration valve of the HAMILTON-C2.

Description: This calibration checks and resets the calibration points specific to the Flow Sensor in use.

Procedure:

1. Set the ventilator up as for normal ventilation, complete with breathing circuit and Flow Sensor.
2. Activate **Flow Sensor** from the **Tests&calib** window.
3. If you have not already disconnected the patient, the message line displays **Disconnect patient**. Disconnect the patient now.
4. Follow the instructions displayed in the message line, turning the Flow Sensor as indicated.
5. VERIFY that the message line displays the green check mark.
If the message line displays the red cross, rerun the test. If the second attempt fails, install a new Flow Sensor.

6. Reconnect the patient, as indicated.

Procedure for infant Flow Sensor:

1. Set the ventilator up as for normal ventilation, complete with breathing circuit, Flow Sensor, and expiratory membrane and cover. Make sure that the **Neonatal** patient group is selected and that the infant Flow Sensor type is installed.
2. Activate **Flow sensor** from the **Tests&calib** window.
3. **If you have not already disconnected the patient, the message line displays Disconnect patient.** Disconnect the patient now.
4. VERIFY that the message line displays the green tick. If the message line displays the red cross, rerun the test. If the second attempt fails, install a new Flow Sensor.
5. Reconnect the patient, and close the **Tests & calib** window.

Corrective action: If the message bar displays **Flow Sensor cal. needed**, run the calibration again. If the calibration still fails, install a new Flow Sensor.

3.3.2.4 Oxygen cell calibration

NOTE:

- The oxygen cell calibration can be performed in the standby mode only.
 - The oxygen cell calibration requires that a HAMILTON MEDICAL oxygen cell be installed and that the ventilator's oxygen monitoring be enabled. To check for an oxygen cell, see Section 10. To determine whether oxygen monitoring is enabled, check the **System -> Sensorson/off** window.
 - If using the low-pressure-mode disconnect all O₂-supplies during calibration. After reconnecting the oxygen concentration is realised at 21 %.
-

Description: During this 2-min calibration of the oxygen cell, the HAMILTON-C2 delivers an increased oxygen concentration (if oxygen is connected in the high pressure mode) or 21 % oxygen (if oxygen is connected in the low pressure mode or disconnected). It tests the cell and resets the calibration points specific to the cell in use.

Procedure:

1. From the **Tests&calib** window, select **O2 cell**.
2. VERIFY that there is a green check mark in the box beside **O2 cell**.

Corrective action:

Troubleshoot any alarms as described in Section 8.

3.3.2.5 CO2 sensor/adaptor zero calibration

NOTE:

- The CO2 sensor and adapter must be disconnected from the patient circuit during the CO2 sensor/ adapter calibration (Figure 3-3), but otherwise the patient may remain connected to the ventilator.
 - The CO2 sensor/adaptor calibration requires that a CO2 sensor be installed, the CO2 hardware option be activated, and that CO₂ monitoring be enabled.
 - Wait at least 20 s -- and for best results, 2 min -- to perform the CO2 sensor/adaptor calibration after removing the adapter from the patient's airway. This time allows any CO₂ remaining in the adapter to dissipate.
 - If you close the **Tests & calib** window when the calibration has failed, the HAMILTON-C2 starts ventilating but continues to display **CO2sensor calibration needed**. This may result in inaccurate monitoring.
 - To calibrate the sidestream sensor disconnect the adapter from the patient circuit (Figure 3-4).
-

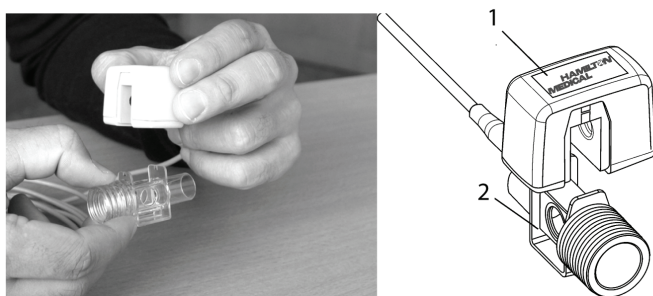


Figure 3-3. Disconnection of the mainstream sensor for calibration

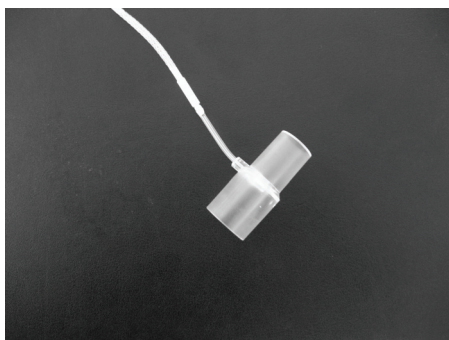


Figure 3-4. Disconnection of the sidestream sensor for calibration

Description: The CO₂ sensor/adapter zero calibration compensates for the optical differences between airway adapters and for sensor drift.

Procedure:

1. Connect the CO₂ sensor with adapter to the ventilator. Do not connect the adapter to the patient circuit. Place the sensor with the adapter installed away from all sources of CO₂ (including the patient's – and your own exhaled

breath) and exhaust port of expiratory valve. Do not agitate the sensor during calibration.

2. From the **Tests & calib** window, select **CO2 sensor**.
3. You will see the message **CO2 calibration in progress**.
4. VERIFY that the message bar displays **CO2 sensor calibrated OK**.
5. Close the **Tests & calib** window.

Corrective action: If the calibration fails, refer to Section 8.

3.3.3 Sensors on/off: Enabling/disabling O2 and CO2 monitoring

CAUTION

The HAMILTON-C2's oxygen monitoring function can be disabled. To prevent possible patient injury due to nonfunctional alarms and monitoring, however, HAMILTON MEDICAL recommends that oxygen monitoring always be enabled.

NOTE:

To enable CO2 monitoring, you must first configure this hardware option on.

Open the **System -> Sensors on/off** window. Select the **O2 cell** and **CO2 sensor** check boxes to enable/disable these monitoring functions, as desired.

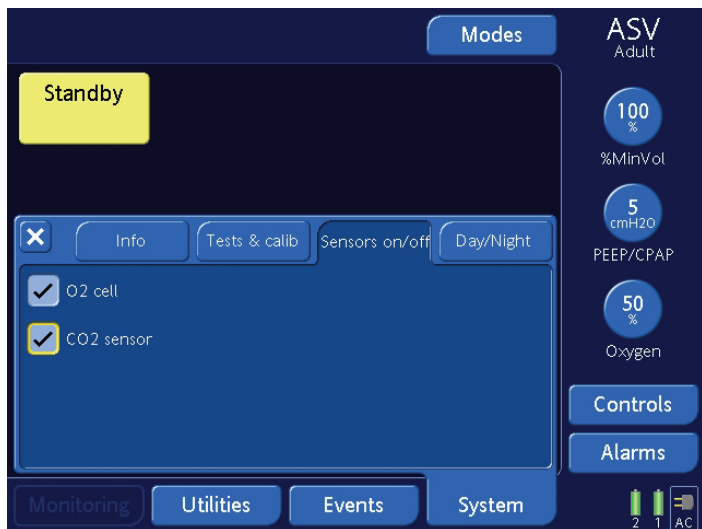


Figure 3-5. Sensor on/off window

3.3.4 Setting day and night

1. Open the **System** -> **Day&Night** window.
2. Switch from day mode to night mode by activating the **Night** button or from night mode to day mode by activating the **Day** button.

Change the brightness of the screen for the day or night mode with the **Brightness** control knob.



Figure 3-6. Day/Night window

3.3.5 Setting date and time

NOTE:

Make sure the date and time are set correctly so that event log entries have accurate time and date stamps.

1. Open the **System** -> **Day/Night** window.
2. Select **Date&Time** and adjust the day and time. **Apply** the changes (Figure 3-7).



Figure 3-7. Date&Time window

3.4 Utilities

You can configure the ventilator and transfer event log data to a USB memory device from the **Utilities** window.

3.4.1 Configuration: Configuring the ventilator

Open the **Utilities** -> **Configuration** window. Enter the code, confirm and select **Configuration** to access the configuration mode, as described in Appendix J.

3.4.2 Data transfer: Copying event log data to a USB memory device

NOTE:

- The USB connector is intended for passive memory devices only.
 - If you remove the memory device before the files are successfully transferred, you must reinitialize the USB port by powering the ventilator off and on again.
 - The USB device must be USB 1.1 compatible.
 - A .jpg file can be stored to the USB over the screen shot key.
-

You can save the event and service logs to a USB memory device. The device must have a FAT or FAT32 format and it must not have an operating system or a security system installed.

To save the logs, place the ventilator into standby and insert a memory device into the USB connector. Open the **Utilities** -> **Datatransfer** window (Figure 3-8 and Figure 3-9), and select **Export logs**. Remove the memory device when **Export successfully done** is displayed.

A folder named "C2_sn<Serial Number>" will be created on the USB stick containing all eventlog and servicelog files.

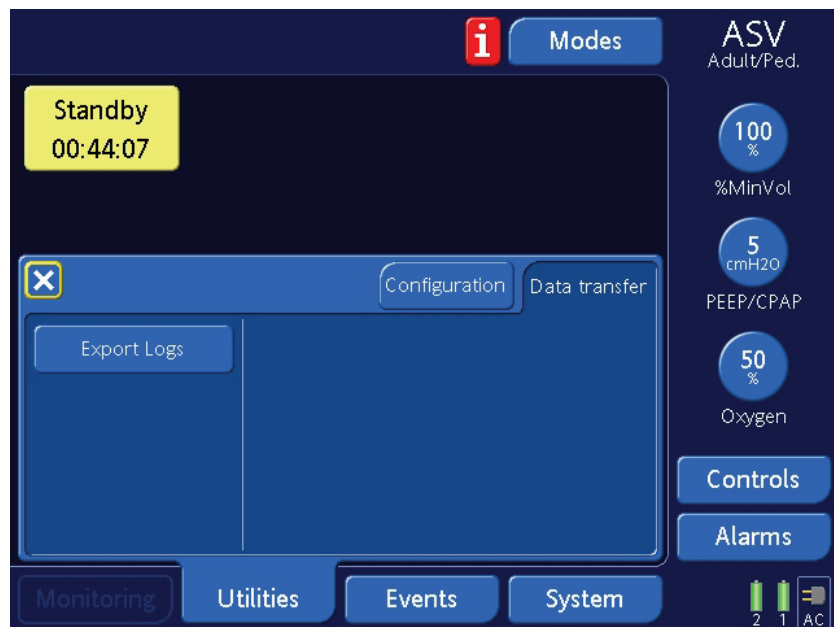


Figure 3-8. Data transfer window 1



Figure 3-9. Data transfer window 2

3.5 Alarm tests

The HAMILTON-C2 performs a self-check during start-up and continuously during operation. This self-check verifies the alarm functionality. You may also want to run alarm tests, which demonstrate the alarms' operation.

Before performing the alarm tests, set the HAMILTON-C2 up as for normal ventilation, complete with breathing circuit and 2 l demonstration lung assembly with ET tube.

3.5.1 High pressure

1. Make sure a 2 l demonstration lung assembly is connected to the ventilator.
2. Put the ventilator into the PCV+ mode.

3. Set the Pressure alarm limit to 15 cmH₂O above the measured P_{peak}.
4. Squeeze the demonstration lung hard during inspiration.
5. VERIFY that the **High pressure** alarm is activated, the ventilator cycles into exhalation, and pressure falls to the PEEP/CPAP level.

3.5.2 Low minute volume

1. Let the ventilator deliver 10 breaths with no alarms.
2. Adjust the minimum ExpMinVol alarm limit so it is higher than the measured value.
3. VERIFY that the **Low minute volume** alarm is activated.

3.5.3 Low oxygen alarm

1. Set the Oxygen control to 50%.
2. Wait for 2 min.
3. Disconnect the oxygen supply.
4. VERIFY that the Oxygen concentration displayed in the monitoring window decreases. VERIFY that the **Low oxygen** alarm activates.
5. Wait 30 s or until the oxygen concentration falls below 40%.
6. Reconnect the oxygen supply.
7. VERIFY that the **Low oxygen** alarm resets. The **Low oxygen** alarm should reset when the measured oxygen exceeds 45%.

3.5.4 Disconnection on patient side

1. Disconnect the demonstration lung.
2. VERIFY that the **Disconnection on patient side** alarm is activated.
3. Reconnect the demonstration lung.

-
4. VERIFY that the alarm resets and that the HAMILTON-C2 automatically resumes ventilation.

3.5.5 Loss of external power

1. With the HAMILTON-C2 connected to AC power, start it up.
2. Disconnect the power cord.
3. VERIFY that the **Loss of external power** alarm is activated and that the HAMILTON-C2 is powered by its backup batteries.
4. Reconnect the HAMILTON-C2 to AC power.
5. VERIFY that the alarm resets and that the HAMILTON-C2 is again powered by AC.

3.5.6 Exhalation obstructed

1. Block the expiratory valve exhaust port.
2. Observe the pressure rise.
3. VERIFY that the **Exhalation obstructed** alarm is activated.

3.5.7 Apnea

1. Put the ventilator into SPONT mode. Make sure apnea backup ventilation is disabled.
2. Wait for the set apnea time.
3. VERIFY that the **Apnea** alarm is activated.
4. Squeeze the demonstration lung.
5. VERIFY that the **Apnea** alarm resets.

4 Ventilator settings

4.1	Introduction	4-2
4.2	Patient grouping	4-2
4.3	Quick start-up settings	4-4
4.4	Patient setup	4-4
4.5	Modes window: Setting the ventilation mode	4-6
4.6	Controls windows: Setting controls including apnea backup ventilation	4-8
4.6.1	Adjusting and confirming control settings without mode change	4-8
4.6.2	Adjusting and confirming control settings after mode change	4-10
4.6.3	About apnea backup ventilation	4-12
4.6.4	Table of control settings, mode additions and ranges.	4-15
4.7	Alarms windows	4-22
4.7.1	Limits 1 and Limits 2: Setting alarm limits	2+23
4.7.2	Loudness: Adjusting alarm loudness	4-25
4.7.3	Buffer: Viewing alarm information	4-26
4.7.4	Table of alarm limit settings and ranges	4-27
4.7.5	TRC: Setting tube resistance compensation	2+29

4.1 Introduction

CAUTION

- To prevent possible patient injury, make sure the ventilator is set up for the appropriate patient type with the appropriate breathing circuit parts as described in Section 2. *Make sure the Flow Sensor calibration and the tightness test is performed before you use the ventilator.*
 - To ensure the ventilator's safe operation, always run the preoperational check before using the ventilator on a patient. If the ventilator fails any tests, remove it from clinical use immediately. Do not use the ventilator until necessary repairs are completed and all tests have passed.
 - It is the clinician's responsibility to ensure that all ventilator settings are appropriate, even when "automatic" features such as ASV or standard settings are used.
-

This section tells you how to set up the HAMILTON-C2 for ventilation on an individual patient. Prepare the ventilator as instructed in Section 2.

You must be familiar with using the touchscreen and knob to select, activate, and confirm parameters. For details, see chapter 2.16.

4.2 Patient grouping

The HAMILTON-C2 facilitates the ventilation of your patient by providing two patient groups, neonatal and adult/pediatric.

Table 4-1. Patient grouping

	Neonatal	Adult/ped.
Patient group	Neonates: From birth to 1 month of age - very low birth weight < 1.5 kg - low birth weight < 2.5 kg	
	Infants: Greater than 1 month to 2 years of age	Infants: Greater than 1 month to 2 years of age
		Childs: Greater than 2 to 12 years of age
		Adolecents: Greater than 12 to 21 years of age
		Adults: Greater than 21 years of age
Specialities	nCPAP-PS	ASV, Dynamic Lung, Ventilation status

Table 4-1 gives an overview of the two patient groups and the corresponding sub-groups.

4.3 Quick start-up settings

The HAMILTON-C2 has three different quick start-up settings per patient group (Figure 4-1). Mode, mode controls settings, alarm settings, ventilation status settings and Vt/IBW can be stored behind each quick start-up.

To configure the quick start-up settings refer to Section J-5.



Figure 4-1. Quick start-up settings (Example)

4.4 Patient setup

NOTE:

If you select the neonatal patient group "Neonatal" appears on the screen (Figure 4-3).

After you initiate ventilation, the patient setup window is shown (Figure 4-2). The default settings are shown. Select, adjust, and activate the desired items. Make sure the ventilator is configured with the appropriate breathing circuit parts, as described in Section 2.5.

1. If you haven't already done so, run the **Preop check**.
2. Select **Adult/Ped.** or **Neonatal**, if you are using this option to ventilate adult-pediatric or neonatal-pediatric.
3. If you selected **Adult/Ped.**, adjust the **Gender** and **Pat. height** settings. The ideal bodyweight (**IBW**) is automatically calculated and displayed¹. If you select **Neonatal** adjust the absolute bodyweight.
4. Select **Start ventilation** to start ventilation.

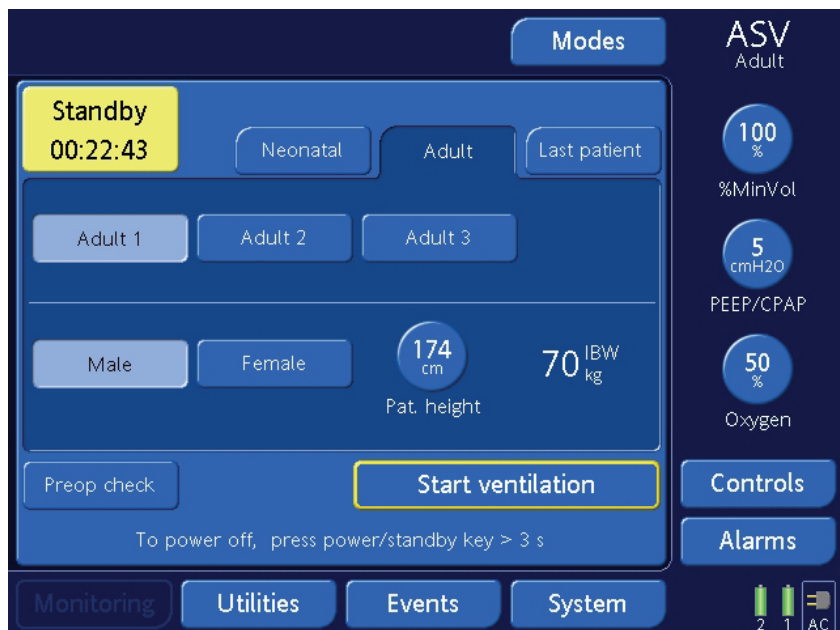


Figure 4-2. Patient setup window

1. The IBW, based on Pennsylvania Medical Center (adults) and Traub SL. Am J Hosp Pharm 1980 (pediatric patients), is calculated as follows:
 IBW: Ideal Body Weight [kg]
 BH: Body Height [cm]
 BH $\leq$ 70 cm

$$\text{IBW} = 0.125 \times \text{BH} - 0.75$$
 70 < BH $\leq$ 128

$$\text{IBW} = 0.0037 \times \text{BH} - 0.4018 \times \text{BH} + 18.62$$
 BH $\geq$ 129
 Male IBW = $0.9079 \times \text{BH} - 88.022$
 Female IBW = $0.9049 \times \text{BH} - 92.006$

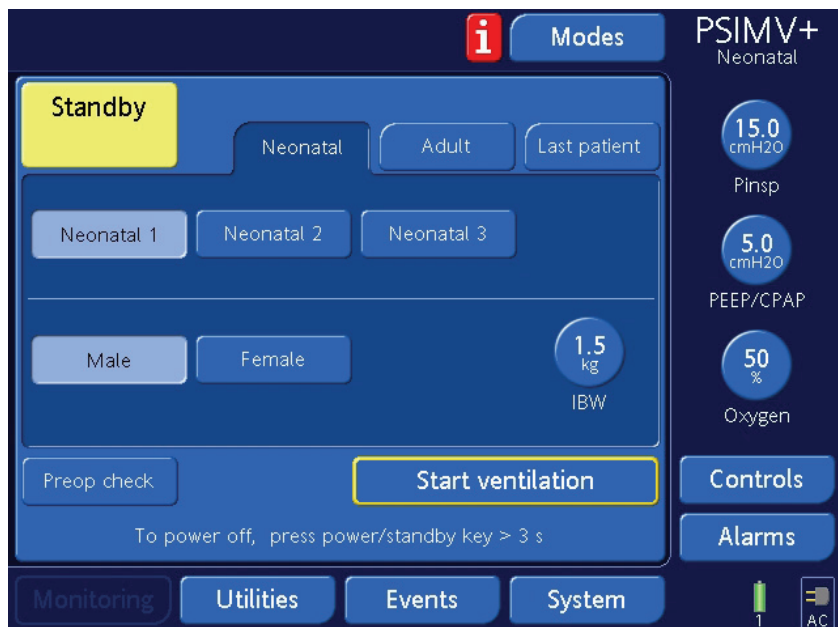


Figure 4-3. Patient setup window neonatal

4.5 Modes window: Setting the ventilation mode

NOTE:

- For details on modes, consult Appendix C (for adaptive support ventilation, ASV), Appendix D (clinical application details for noninvasive ventilation), or Appendix B (for all other modes).
- ASV mode applies only for adults. nCPAP-PS is optional for neonates.

The active ventilation mode is displayed at the top right-hand corner of the screen. Change the mode as follows:

1. Open the **Modes** window (Figure 4-4).
2. Select a mode.

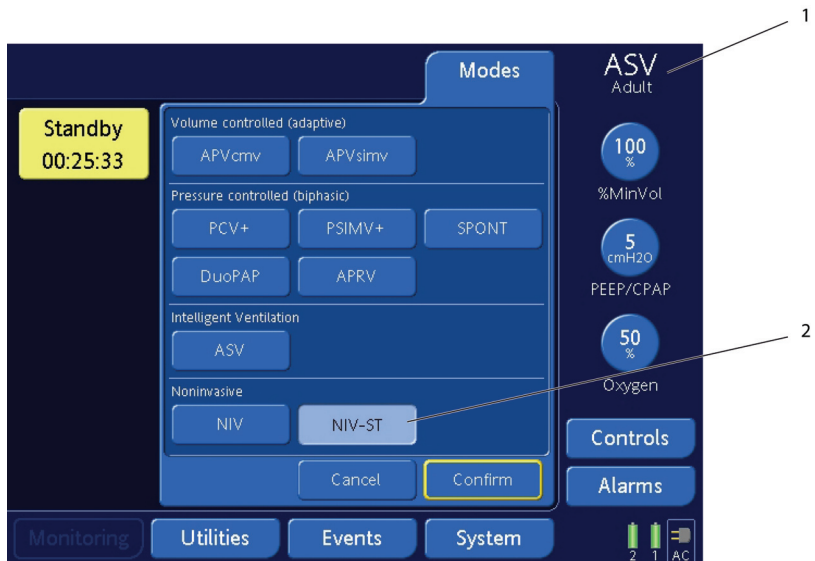


Figure 4-4. Modes window

- 1 Active mode
- 2 New selected mode
3. **Confirm** the mode. The controls window opens automatically. Review and confirm the control settings (see Section 4.4.2). If the control settings are not confirmed, the window automatically closes after a period of time. The new mode selection will not be valid, and the previous settings remain in effect.

4.6 Controls windows: Setting controls including apnea backup ventilation

NOTE:

- In addition to control settings, the **Basic** window displays breath timing parameters determined from timing control settings; see Figure 4-8.
 - If you intend to use the nCPAP-PS mode or the non-invasive ventilation modes (NIV or NIV-ST), we recommend that you consult Appendix D for more details.
-

You can set controls from the three **Controls** windows: **Basic**, **More**, and **Apnea**. You enable the sigh function through the **More** window. You can set apnea backup through the **Apnea** window. Table 4-2 is an alphabetical list of the control settings with their ranges. For control setting ranges and standard settings, see Table A-6. For control settings applicable to the different ventilation modes, see Table A-7.

4.6.1 Adjusting and confirming control settings without mode change

NOTE:

Also change PEEP/CPAP, Oxygen, and one additional control setting from the basic screen without opening the **Controls** window.

Change the control settings at any time as follows:

1. Open the **Controls** -> **Basic** window (Figure 4-5).
2. Select a parameter and adjust the value. The change takes effect immediately. Repeat for any other desired parameters.
3. Open the **Controls** -> **More** window (Figure 4-6), and select and adjust parameters as desired.

4. If applicable, open the **Controls** -> **Apnea** window. Select or deselect **Backup** as desired. The backup mode and settings are displayed (see chapter 4.4.3).

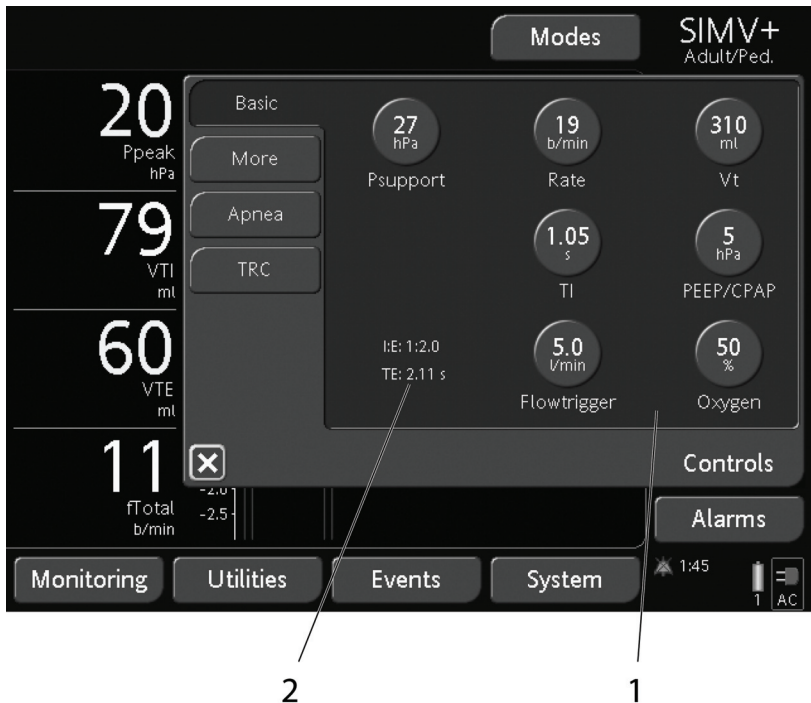


Figure 4-5. Basic (Controls) window

- 1 Control settings correspond to the mode
- 2 Timing parameters, determined from the timing settings (if control breaths are permitted in selected mode):

I:E: Ratio of inspiratory time. Applies mandatory breaths.

TE: Duration of expiratory phase

TI: Duration of inspiratory phase

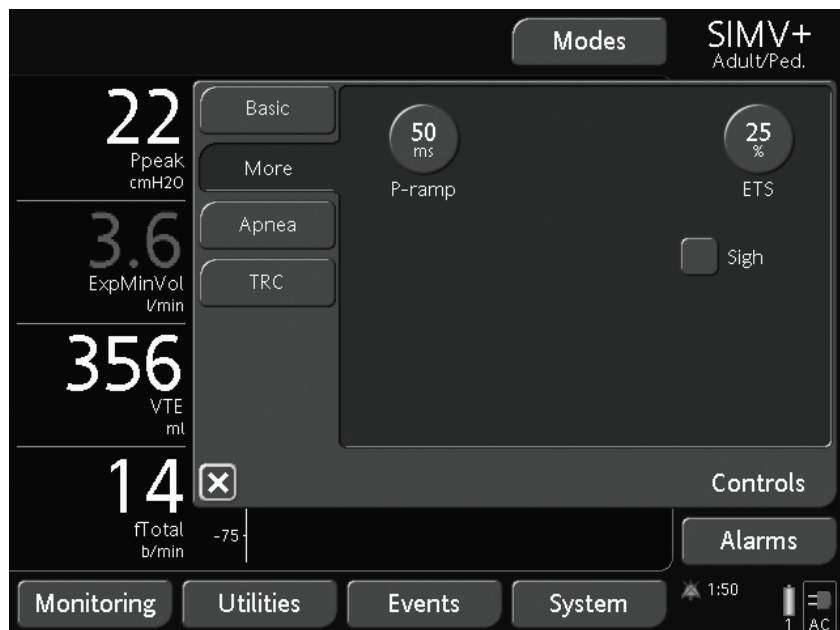


Figure 4-6. More window

4.6.2 Adjusting and confirming control settings after mode change

After you select a different mode, the **Basic** window automatically opens (Figure 4-8). Review and confirm these proposed settings or the mode change will not be accepted.

Review and confirm the control settings as follows:

1. Select a parameter and adjust the value. The change takes effect as soon as you confirm the mode change. Repeat for any other desired parameters.
2. Open the **Controls** -> **More** window (Figure 4-6), and select and adjust parameters as desired.
3. If applicable, open the **Controls** -> **Apnea** window. Select or deselect **Backup** as desired. The backup mode and settings are displayed. See chapter 4.4.3 for further details on how apnea backup functions.

4. Open **Controls**-> **TRC** window. Adjust parameters as desired (see the TRC chapter in this Section).

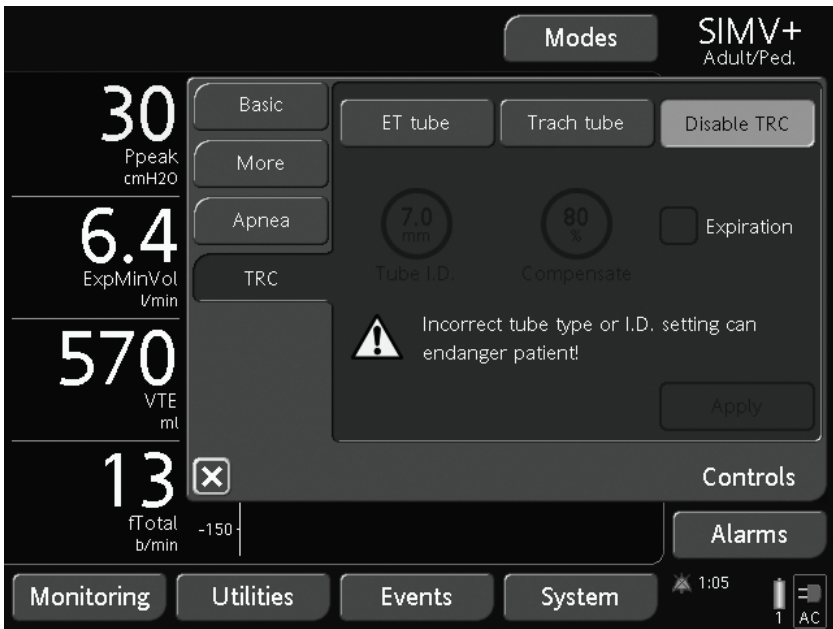


Figure 4-7. TRC window

5. Confirm by selecting **Apply**.

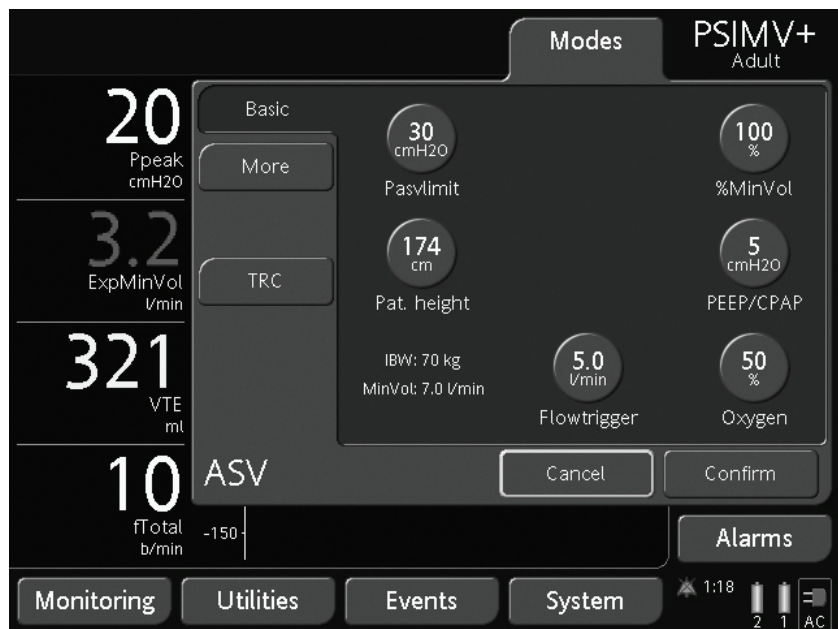


Figure 4-8. Basic window during mode change (ASV mode change)

4.6.3 About apnea backup ventilation

CAUTION

HAMILTON MEDICAL recommends that apnea backup ventilation be enabled whenever a mode that allows spontaneous breathing is selected. For safety reasons, apnea backup is enabled by default.

The HAMILTON-C2 provides apnea backup ventilation, a mechanism that minimizes possible patient injury due to apnea or cessation of respiration. Apnea can occur in all modes except (S)CMV+, PCV+, ASV, PSIMV+, NIV-ST and nCPAP-PS. When the HAMILTON-C2 is in such a mode and no inspiratory efforts are detected or control breaths are delivered during an operator-set interval, it assumes that apnea is present. If apnea backup ventilation is enabled, ventilation continues.

When apnea backup ventilation is enabled. Apnea backup provides ventilation after the apnea time passes with no breath attempts detected. (You set the **Apnea time** in the **Alarms** window.) When this occurs, the HAMILTON-C2 automatically and immediately switches into apnea backup ventilation. It annunciates a low-priority alarm, displays **Apnea ventilation**, and provides ventilation at the following settings:

If the original support mode is...	the HAMILTON-C2 enters this backup mode...
SIMV+/APVsimv	SIMV+ /APVsimv
SPONT	SIMV+
DuoPAP/APRV	SIMV+
NIV	PCV+
nCPAP-PS	PCV+

The control setting for the apnea backup mode depends on the ideal body weight of the patient. The default values can be overwritten by disabling the **Automatic** button.

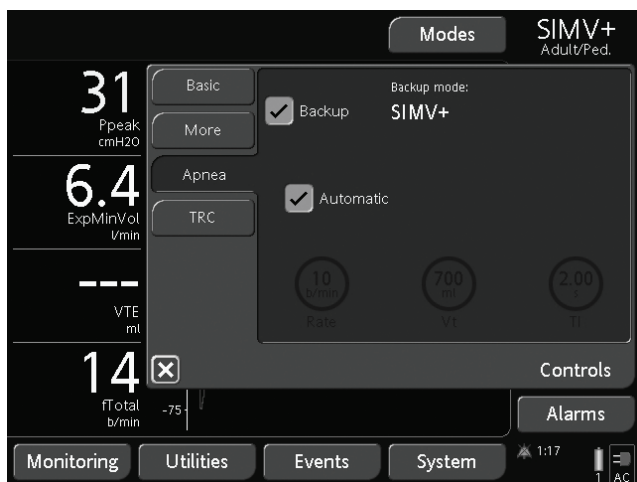


Figure 4-9. Automatic button

If the patient triggers two consecutive breaths, the HAMILTON-C2 reverts to ventilation in the original support mode and at the original settings, and it displays **Apnea ventilation ended**.

Once apnea backup ventilation is enabled or disabled, it retains this status in all applicable modes. Apnea backup ventilation requires no clinician intervention, although you can freely change the mode during apnea backup ventilation, either switching to a new mode or accepting the backup mode as the new mode.

When apnea backup ventilation is disabled, the high-priority **Apnea** alarm is annunciated when apnea occurs.

4.6.4 Table of control settings, mode additions and ranges.

Table 4-2. Control settings, mode additions and ranges

Parameter	Definition	Range	
		Adult	Neonatal
Apnea (back up)	A function that provides ventilation after the adjustable apnea time passes without breath attempts. Applies in SIMV+, SPONT, NIV, APRV, DuoPAP. If "Automatic" is enabled, control parameters are calculated based on the patients IBW.	On or Off	On or Off
ETS	Expiratory trigger sensitivity. The percent of peak inspiratory flow at which the ventilator cycles from inspiration to exhalation. Increasing the ETS setting results in a shorter inspiratory time, which may be beneficial in patients with obstructive lung disease. The ETS setting lets you match the inspiratory time of pressure-supported breaths to the patient's neural timing. Applies to spontaneous breaths.	5 to 80% (of inspiratory peak flow)	5 to 80% (of inspiratory peak flow)

Table 4-2. Control settings, mode additions and ranges (continued)

Parameter	Definition	Range	
		Adult	Neonatal
Flowtrigger	The patient's inspiratory flow that triggers the ventilator to deliver a breath. The HAMILTON-C2 generates a continuous and constant base flow from the inspiratory outlet to the expiratory outlet during the later part of exhalation. Base flow is essential for flow trigger. This base flow ranges from 4 to 20 l/min depending on the setting. Applies to all breaths. NOTE: If autotriggering occurs, first check the patient, breathing circuit, and other settings as possible causes before decreasing the trigger sensitivity.	Off, 1.0 to 20 l/min ((S)CMV+ and PCV+ modes) 1.0 to 20 l/min (other modes)	Off, 0.1 to 20 l/min ((S)CMV+ and PCV+ modes) 0.1 to 20 l/min (other modes)
Gender	Sex of patient. Used to compute ideal body weight (IBW).	Male, Female	--
I:E	Ratio of inspiratory time to expiratory time. Applies to mandatory breaths. Applies in (S)CMV+ and PCV+.	1:9.0 to 4.0:1 (1:599 to 74:1 in APRV/Duo-PAP)	--
Ideal body weight (IBW)	A valid relation between age, size or weight and start-up values has to be specified. Used only for neonates.	--	0.2 to 30 kg
Loudness	Alarm loudness.	1 to 10	1 to 10

Table 4-2. Control settings, mode additions and ranges (continued)

Parameter	Definition	Range	
		Adult	Neonatal
%MinVol	Percentage of minute volume to be delivered. The HAMILTON-C2 uses the %MinVol, Pat. height, and Gender settings to calculate the target minute ventilation. The %MinVol for a normal patient might be 100% (100 ml/min/kg body weight for adults and 300 ml/min/kg body weight for pediatric patients); for a COPD patient, 90%; for an ARDS patient, 120%; and for other patients, 110%. Add 20% if body temperature > 38.5 °C (101.3 °F) and 5% per 500 m (1640 ft) above sea level. Applies in ASV (see).	25 to 350%	--
Oxygen	Oxygen concentration to be delivered. Applies to all breaths. Not active when low-pressure oxygen is used.	21 to 100%	21 to 100%
Pasvlimit	Maximum pressure to be applied. For the ASV controller to function correctly, Pasvlimit must be at least 15 cmH ₂ O above PEEP/CPAP. Changing Pasvlimit or the Pressure alarm limit automatically changes the other: Pressure is always 10 cmH ₂ O greater than Pasvlimit. Applies only in ASV mode.	5 to 60 cmH ₂ O	--
Pat. height	Patient height. It determines the ideal bodyweight (IBW), which is used in calculations for ASV and start-up settings.	30 to 250 cm	--

Table 4-2. Control settings, mode additions and ranges (continued)

Parameter	Definition	Range	
		Adult	Neonatal
Pcontrol	Pressure (additional to PEEP/CPAP) to be applied during the inspiratory phase. Applies in PCV+.	5 to 60 cmH ₂ O (above PEEP/CPAP)	3 to 60 cmH ₂ O (above PEEP/CPAP)
PEEP/CPAP	PEEP (positive end expiratory pressure) and CPAP (continuous positive airway pressure), base-line pressures applied during the expiratory phase. Applies to all breaths.	0 to 35 cmH ₂ O	0 to 25 cmH ₂ O
P high	Applies in DuoPAP and APRV. Absolute pressure, includes PEEP.	0 to 60 cmH ₂ O	0 to 60 cmH ₂ O
Pinsp	Pressure (additional to PEEP/CPAP) to be applied during the inspiratory phase. Applies in PSIMV+, NIV-ST, and nCPAP-PS.	5 to 60 cmH ₂ O (above PEEP/CPAP)	0 to 60 cmH ₂ O (above PEEP/CPAP)
P low	Applies in APRV.	0 to 35 cmH ₂ O	0 to 25 cmH ₂ O

Table 4-2. Control settings, mode additions and ranges (continued)

Parameter	Definition	Range	
		Adult	Neonatal
P-ramp	Pressure ramp. Time required for inspiratory pressure to rise to the set (target) pressure. The P-ramp setting lets you fine-tune the initial flow output during a pressure-controlled or pressure-supported breath to match the ventilator flow to the patient's demand. Short P-ramp settings (0 to 50 ms) provide higher initial flow rates and result in faster attainment of the target pressure. This may benefit patients with elevated respiratory drive. Setting the P-ramp too low, especially in combination with a small ET tube (high resistance), may result in a noticeable pressure overshoot during the early stage of inspiration and a Pressure limitation alarm. Setting the P-ramp too high may prevent the ventilator from attaining the set inspiratory pressure. A square (rectangular) pressure profile is the goal. Lower P-ramp values have been correlated with reduced work of breathing in certain patients.	0 to 2000 ms	0 to 2000 ms

Table 4-2. Control settings, mode additions and ranges (continued)

Parameter	Definition	Range	
		Adult	Neonatal
	Applies to all breaths. NOTE: To prevent possible pressure overshoot in pediatric applications, it is recommended that P-ramp be set to at least 75 ms.		
Psupport	Pressure support. Pressure (additional to PEEP/CPAP) to be applied during the inspiratory phase. Pressure support helps the patient counteract the flow resistance of the breathing circuit and endotracheal tube. It compensates for the decreasing tidal volume and rising respiratory rate of a spontaneously breathing patient. Applies to spontaneous breaths in SPONT, NIV, and SIMV+.	0 to 60 cmH ₂ O (above PEEP/CPAP)	0 to 60 cmH ₂ O (above PEEP/CPAP)
Rate	Respiratory frequency or number of breaths per minute. Applies in (S)CMV+, PCV+. Applies in PSIMV+, NIV-ST. Applies in SIMV+, DuoPAP and nCPAP-PS.	4 to 80 b/min. 5 to 80 b/min. 1 to 80 b/min.	15 to 150 b/min. 15 to 150 b/min. 1 to 150 b/min.

Table 4-2. Control settings, mode additions and ranges (continued)

Parameter	Definition	Range	
		Adult	Neonatal
Sigh	Breaths delivered at a regular interval (every 50 breaths) at a pressure up to 10 cmH ₂ O higher than non-sigh breaths, as allowed by the Pressure alarm limit. During sigh breaths, the Pressure and Vt alarm limits remain in effect to help protect the patient from excessive pressures and volumes. Applies in all modes except DuoPAP and APRV.	On or Off	--
T high	Applies in DuoPAP and APRV.	0.1 to 40 s	0.1 to 40 s
TI	Time to deliver the required gas (time to reach the operator-set Vt or Pcontrol value). Applies in SIMV+, PSIMV+, NIV-ST and nCPAP-PS.	0.1 to 12 s	0.1 to 12 s
TI max	Maximum inspiratory time for flow cycled breaths. Applies in NIV, NIV-ST and nCPAP-PS.	1 to 3 s	0.25 to 3 s
T low	Applies in APRV.	0.2 to 40 s	0.2 to 40 s

Table 4-2. Control settings, mode additions and ranges (continued)

Parameter	Definition	Range	
		Adult	Neonatal
TRC	Tube resistance compensation. Reduces the patient's work of breathing by offsetting tube resistance. NOTE: If autotriggering occurs, first check the patient, breathing circuit, and other settings as possible causes before lowering the Compensate setting		
Tube type/ TRC disabled	Endotracheal (ET) tube, tracheostomy (Trach) tube, or TRC off.	ET tube, Trach tube, Disable	ET tube, Trach tube, Disable
Tube size	Inner diameter (ID) of tube.	3.0 to 10.0 mm	2.5 to 5.0 mm
Compensate	Percentage of compensation.	0 to 100%	0 to 100%
TRC expiration		ON, OFF	ON, OFF
Vt	Tidal volume delivered during inspiration. Applies in (S)CMV+ and SIMV+.	20 to 2000 ml	2 to 300 ml
VT/kg	Tidal volume per weight	7 to 12 ml/kg	6 to 12 ml/kg

4.7 Alarms windows

Set alarm limits, adjust the alarm loudness, and view active alarms in the **Alarms** windows.

4.7.1 Limits 1 and Limits 2: Setting alarm limits

CAUTION

To prevent possible patient injury, make sure the alarm limits are appropriately set before you place the patient on the ventilator.

NOTE:

If the ventilator is in the (S)CMV+, or SIMV+ mode, be sure the Pressure alarm is appropriately set. This alarm provides a safety pressure limit for the HAMILTON-C2 to appropriately adjust the inspiratory pressure necessary to achieve the target tidal volume. **The maximum available inspiratory pressure is 10 cmH₂O below the Pressure limit, indicated by a blue line on the pressure waveform display.** Set Pressure to a safe value (e.g., 45 cmH₂O, which limits the pressure target to a maximum of 35 cmH₂O). If Pressure is set too low, there may not be enough margin for the HAMILTON-C2 to adjust its inspiratory pressure in order to deliver the target tidal volume.

Access the **Alarms** window and change alarm settings at any time, without affecting ventilation.

The HAMILTON-C2 offers two alarm-setting options:

- Set alarm limits individually.

Review and adjust the alarm limits as follows:

1. Open the **Alarms** -> **Limits1** window (Figure 4-10).
 2. Select a parameter and adjust the value. Repeat for any other desired parameters. Open the **Limits2** window (Figure 4-11) and repeat as desired.
- Using the **Auto** alarm function, you can automatically set all alarm limits around the current monitoring parameters.

Review and adjust the alarm limits as follows:

1. Open the **Alarms** -> **Limits1** window (Figure 4-10).
2. Press the **Auto** button to adjust all alarms to the current patient conditions.

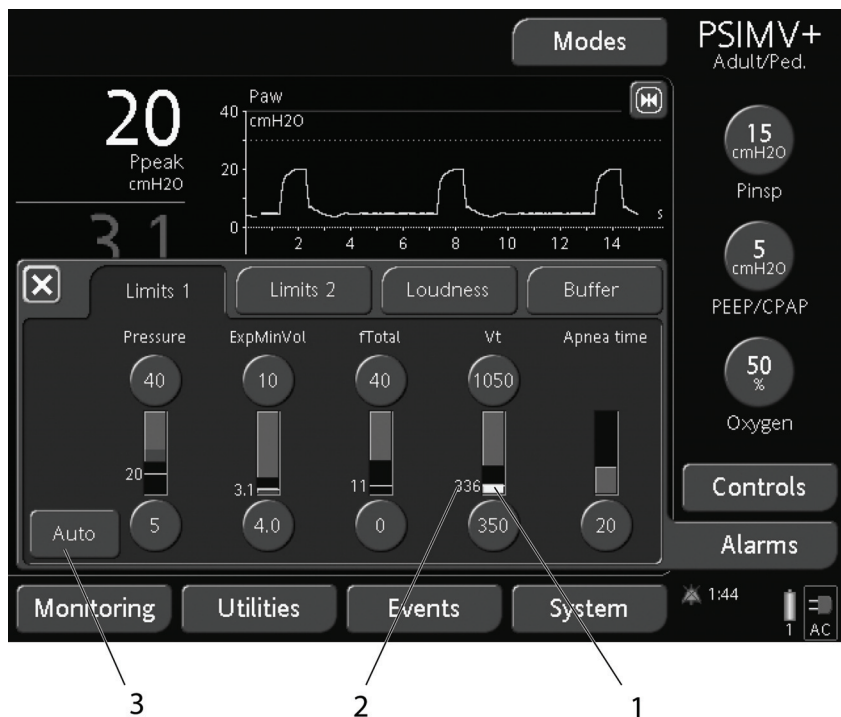


Figure 4-10. Limits 1 window

- 1 Red bar or yellow (depending on alarm priority, low or medium) indicates the monitored value is out of range.
- 2 Actual monitored value
- 3 **Auto** button



Figure 4-11. Limits 2 window

4.7.2 Loudness: Adjusting alarm loudness

NOTE:

- If the alarm loudness was set to < 5 before the ventilator was powered off, the loudness setting will default to 5 when the HAMILTON-C2 is powered on.
- If you decrease the alarm loudness during the night shift, do not forget to return it to its daytime setting!

Adjust the alarm loudness as follows:

1. Open the **Alarms** -> **Loudness** window (Figure 4-12).
2. Adjust the **Loudness** value as desired. **Test** the loudness as desired.
3. Repeat the process as required.



Figure 4-12. Loudness window

4.7.3 Buffer: Viewing alarm information

See Section 8 for a description of the alarm buffer.

4.7.4 Table of alarm limit settings and ranges

Table 4-3. Alarm limit settings and ranges

Parameter	Definition	Range	
		Adult	Neonatal
Apnea time	The maximum time allowed from the beginning of one inspiration to the beginning of the next inspiration. If the patient does not trigger a breath during this time, an alarm is annunciated. Apnea backup ventilation will begin, if enabled.	15 to 60 s	5 to 60 s
ExpMinVol (low and high)	Low and high expiratory minute volume. If either limit is reached, a high-priority alarm is annunciated.	Low: Off, 0.1 to 50.0 l/min (NIV, NIV-ST); 0.1 to 50.0 l/min (other modes) High: 0.1 to 50 l/min	Low: Off, 0.01 to 10 l/min (NIV, NIV-ST and nCPAP-PS); 0.01 to 50.0 l/min (other modes) High: 0.03 to 10 l/min
fTotal (low and high)	Low and high monitored total breath rate (fTotal), including both spontaneous and mandatory breaths. If either limit is reached, a medium-priority alarm is annunciated.	Low: 0 to 99 b/min High: 0 to 99 b/min	Low: 0 to 200 b/min High: 2 to 210 b/min
Oxygen (low and high)	Low and high monitored oxygen concentration (Oxygen). If either limit is reached, a high-priority alarm is annunciated. Applies only when low-pressure oxygen is used.	Low: 18 to 97% High: 18 to 103%	Low: 18 to 97% High: 18 to 103%

Table 4-3. Alarm limit settings and ranges (continued)

Parameter	Definition	Range	
		Adult	Neonatal
PetCO ₂ (low and high)	Low and high monitored PetCO ₂ . If either limit is reached, a medium-priority alarm is annunciated.	Low: Off, 0 to 100 mmHg High: Off, 1 to 100 mmHg	Low: Off, 0 to 100 mmHg High: Off, 1 to 100 mmHg
Pressure (low and high)	Low and high monitored pressure at the patient airway (Ppeak). If pressure (high) is reached or pressure (low) is not reached, a high-priority alarm is annunciated. In addition, when pressure (high) reaches Pressure minus 10 cmH ₂ O, pressure is limited: no further pressure is applied. If pressure (high) is reached, the ventilator immediately stops gas flow to the patient and opens the expiratory valve to reduce pressure to the PEEP/CPAP level. The ventilator is designed to limit patient airway pressure to 60 cmH ₂ O, but if pressure climbs to 75 cmH ₂ O, the ambient valve opens, releasing pressure to the ambient level. An exception is sigh breaths, when the ventilator may apply inspiratory pressure 3 cmH ₂ O below the Pressure alarm limit.	Low: 4 to 60 cmH ₂ O High: 20 to 70 cmH ₂ O	Low: 4 to 60 cmH ₂ O High: 20 to 70 cmH ₂ O
Vt (low and high)	Low and high expiratory tidal volume, for two consecutive breaths. If either limit is reached, a medium-priority alarm is annunciated.	Low: Off, 10 to 3000 ml High: Off, 10 to 3000 ml	Low: Off, 0.1 to 300 ml High: Off, 0.1 to 300 ml

4.7.5 TRC: Setting tube resistance compensation

TRC

WARNING

- **Using the incorrect tube type or size setting can endanger the patient. To prevent possible patient injury due to inappropriate compensation, make sure to set these appropriately.**
 - **TRC may induce autotriggering. If autotriggering occurs, first check the patient, breathing circuit, and other settings as possible causes before lowering the Compensate setting or disabling TRC.**
-

NOTE:

- TRC is intended for use with spontaneously breathing patients.
 - When TRC is enabled, the displayed Ppeak may be higher than the set PEEP/CPAP plus Pcontrol/Psupport, due to the additional pressure required to work against the tube resistance. Look closely at the calculated tracheal pressure, which is simultaneously displayed as an orange waveform.
 - The tracheal pressure waveform displayed is calculated from the proximal flow and pressure signals rather than measured.
 - 100% compensation means that all resistance due to the tube itself is compensated. Internal resistance (for example, from secretions) and external resistance (for example, from tube kinking) is not compensated.
-

To reduce the patient's work of breathing while on the HAMILTON-C2, the ventilator's tube resistance compensation (TRC) feature offsets the flow resistance imposed by the endotracheal (ET) or tracheostomy (Trach) tube. TRC is active during inhalation. The compensation during exhalation can be optionally set.

Enable or disable TRC and adjust the settings as follows:

1. Open the **Controls** -> **TRC** window.

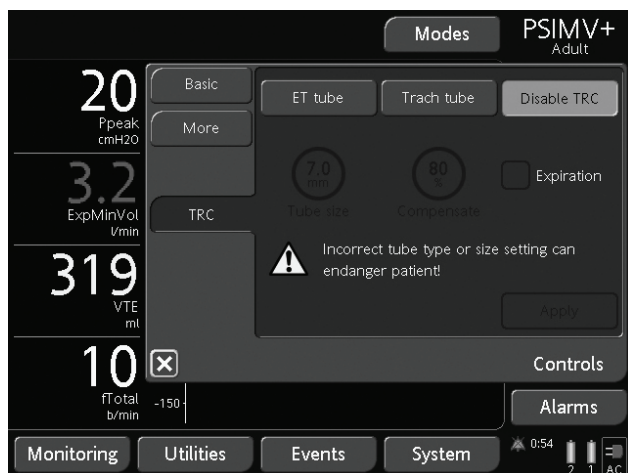


Figure 4-13. TRC window

2. Select **ET tube** (endotracheal tube), **Trach tube** (tracheostomy tube), or **Disable TRC**.
3. If you selected **ET tube** or **Trach tube**, adjust the **Tube ID** and **Compensate** settings. If the ET tube is shortened, lower the **Compensate** setting.
4. Select **Expiration** to activate compensation during exhalation.
5. Confirm by selecting **Apply**.

When TRC is enabled, the orange tracheal pressure waveform, Ptrach, is also shown with the yellow airway pressure waveform, Paw (Figure 4-14).

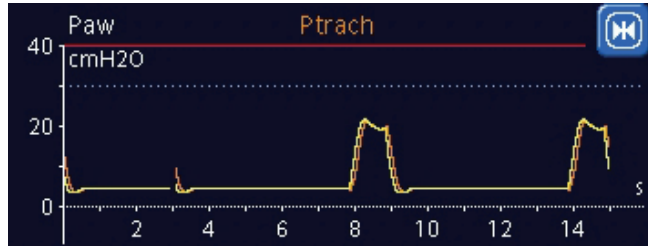


Figure 4-14. Ptrach and Paw waveforms (with TRC active)

5 Neonatal ventilation

5.1	Breathing circuit	5-2
5.2	Flow Sensor	5-2
5.3	Testing and calibration	5-3
5.4	Ventilation modes and mode additions	5-3
5.5	Controls	5-3
	5.5.1 Ti max	5-4
	5.5.2 Flowtrigger	5-4
	5.5.3 P-ramp	5-4
5.6	Others	5-4

WARNING

To prevent possible patient injury, make sure the ventilator is set up correctly for the neonatal patient. The ventilator must have the appropriate breathing circuit parts, including the neonatal Flow Sensor, as described in Section 2. *Make sure the Flow Sensor calibration and the tightness test is performed before you use the ventilator.*

You can use the HAMILTON-C2 to ventilate neonatal patients starting at 0.2 kg. Although the procedure for ventilating neonates is almost identical to that for ventilating other patients, there are some important differences. This section points out these differences, and is intended to supplement the rest of the manual.

5.1 Breathing circuit

WARNING

To prevent breathing difficulties resulting from blocked gas passages, pay attention to possible kinking of very thin neonatal ET tubes.

Dead-space ventilation is harmful and can easily occur at any tidal volume.

NOTE:

To determine appropriate tidal and minute volumes for neonatal patients, you must consider (anatomic) dead space. Artificial airways (Y-piece, Flow Sensor, ET tube, CO2 airway adapter, etc.) may increase the dead space dramatically.

A heating wire may noticeably increase the inspiratory resistance of the neonatal breathing circuit.

5.2 Flow Sensor

Use a HAMILTON MEDICAL infant Flow Sensor (chamber: 0.9 ml) to ventilate your neonatal patient. Do not use an adult Flow Sensor. The neonatal Flow Sensor has a dead space of < 1.3 ml.

Calibrate the neonatal Flow Sensor between patients, after installing a new Flow Sensor, or whenever the **Flow Sensor cal. needed** alarm is activated. Unlike for the adult Flow Sensor calibration, do not turn the neonatal Flow Sensor during calibration. During Flow Sensor calibration, the HAMILTON-C2 can recognize a mismatch between the set patient type and the Flow Sensor in use. In response it annunciates a **Wrong Flow Sensor** alarm.

5.3 Testing and calibration

Just as you would do for any patient, you must run the preoperational check described in before placing your neonatal patient on the ventilator. This test includes a test for leak-tightness of the breathing circuit, calibration of the infant Flow Sensor, and a preoperational check of the HAMILTON-C2 geared for an neonate.

5.4 Ventilation modes and mode additions

WARNING

Auto triggering is harmful and easy to happen at sensitive trigger settings because of the gas leaks around ET tubes.

NOTE:

Because neonatal ET tubes normally do not have a cuff, leakage can be significant (that is, VLeak can be much greater than the measured expiratory tidal volume (VTE)). Check the VLeak parameter in the monitoring window from time to time; the leak may not be predictable.

To ventilate neonatal patients, you must first select and activate the **Neonatal** patient type.

All neonatal modes available in the HAMILTON-C2 are pressure controlled and regulated modes. These include: PCV+, PSIMV+, (S)CMV+, SIMV+, DuoPAP, APRV, SPONT and nCPAP-PS.

5.5 Controls

The following controls require special consideration when setting up the ventilator for an neonatal patient.

Table A-6 lists standard settings applicable to neonatal patients.

5.5.1 Ti max

Ti max (maximum inspiratory time) is set for spontaneous breaths, in non invasive modes (NIV, NIV-ST, and nCPAP-PS). For all patient types, the switchover from inspiration to exhalation in spontaneous breaths is normally controlled by the ETS (expiratory trigger sensitivity). If gas leakage is significant, however, the set ETS may never be reached. The Ti max setting provides a backup so inspiration can be terminated. The HAMILTON-C2 switches over to exhalation when the set Ti max is reached.

5.5.2 Flowtrigger

When flow triggering is active, at the late stage of exhalation the ventilator delivers a constant base flow from the inspiratory limb to the expiratory limb. The base flow is minimally 2 l/min and may be as high as 30 l/min, depending on the set Flowtrigger sensitivity setting.

5.5.3 P-ramp

If an neonatal patient has stiff lungs (for example, RDS), be careful when using a short P-ramp (pressure rise time). A very short P-ramp in this case may cause pressure overshoot.

5.6 Others

WARNING

Prolonged exposure to high oxygen concentrations may cause irreversible blindness and pulmonary fibrosis in preterm neonates.

High rate settings, very short TI or TE may cause incomplete inspiration or expiration.

NOTE:

Nebulization is disabled in the neonatal application.

During the O₂ enrichment maneuver the applied oxygen concentration is increased by 25% of the last oxygen setting (eg. last oxygen setting 40%, resulting oxygen concentration during O₂ enrichment maneuver 50%). The actually applied oxygen concentration is displayed on the oxygen control knob (green). Oxygen enrichment continues for 2 min unless you terminate it by pressing the O₂ enrichment key again or manually activating and confirming the oxygen control knob.

6 Monitoring

6.1	Introduction	6-2
6.2	Values window: Viewing numeric patient data	6-4
6.3	Graphics window: Selecting second screen graphic	6-7
6.4	About graphic types	6-8
	6.4.1 Waveforms	6-8
	6.4.2 Dynamic Lung	6-9
	6.4.3 Vent Status	6-9
6.5	Trends	6-10
6.6	Loops	6-12
6.7	Table of monitored parameters	6-14
6.8	Freeze and cursor measurement	6-23

6.1 Introduction

CAUTION

- To ensure that oxygen monitoring is always fully functional, replace an exhausted or missing oxygen cell as soon as possible or use an external monitor that complies with ISO 21647.
 - The ventilator's oxygen monitoring function can be disabled. To prevent possible patient injury due to nonfunctional alarms and monitoring, however, HAMILTON MEDICAL recommends that oxygen monitoring always be enabled.
 - In case of malfunction of the ventilator's built-in monitoring and in order to maintain an adequate level of patient monitoring at all times, it is recommended that additional independent monitoring devices be used. The operator of the ventilator must still maintain full responsibility for proper ventilation and patient safety in all situations.
-

During ventilation, you can view patient data on the HAMILTON-C2 screen (Figure 6-1). You can configure the screen layout with different waveforms, loops or trends, or with Intelligent Panel graphics to suit your institution's needs. Access the **Monitoring** window at any time without affecting breath delivery.

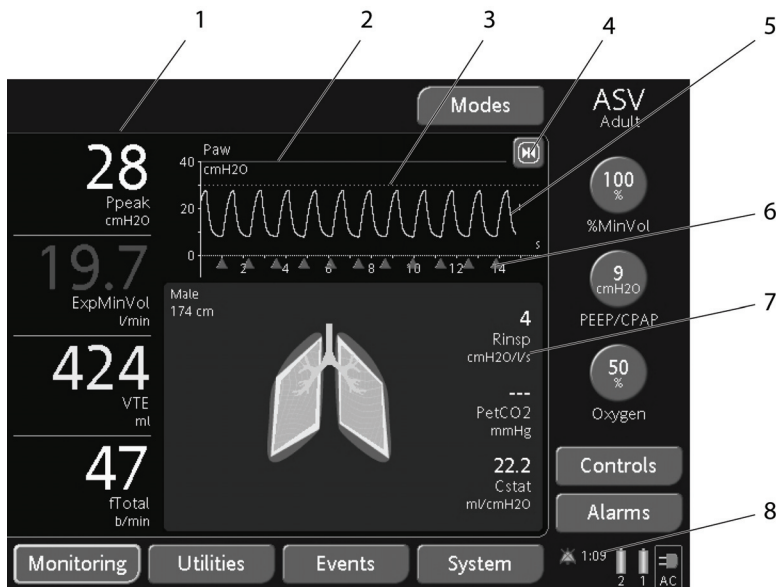


Figure 6-1. HAMILTON-C2 screen

- 1** Main monitoring parameters (MMP)
- 2** Pressure high alarm limit
- 3** Pressure limitation: (Pressure alarm line - 10 cmH2O)
- 4** Freeze button
- 5** Airway pressure (Paw) waveform (standard graphic 1)
- 6** Patient trigger indicator
- 7** Dynamic Lung (selectable graphic 2)
- 8** Time remaining until next alarm (silence alarm)

6.2 Values window: Viewing numeric patient data

You can view numeric patient data from the **Values** window. Figure 6-2 through Figure 6-5 describes the monitored parameters.

1. Open the **Monitoring** -> **Values** window.
2. Select **1**, **2**, **3** or **CO2** to show numeric patient data.

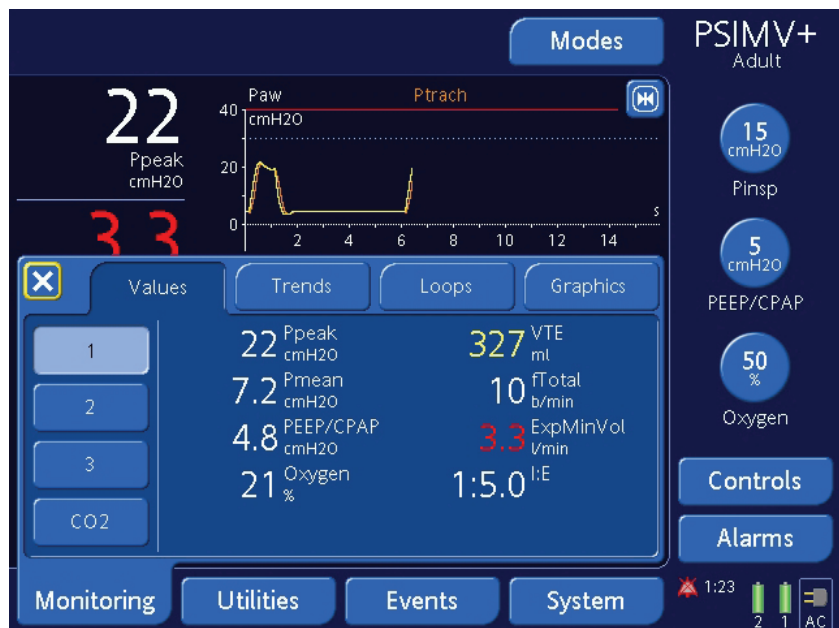


Figure 6-2. Values window 1

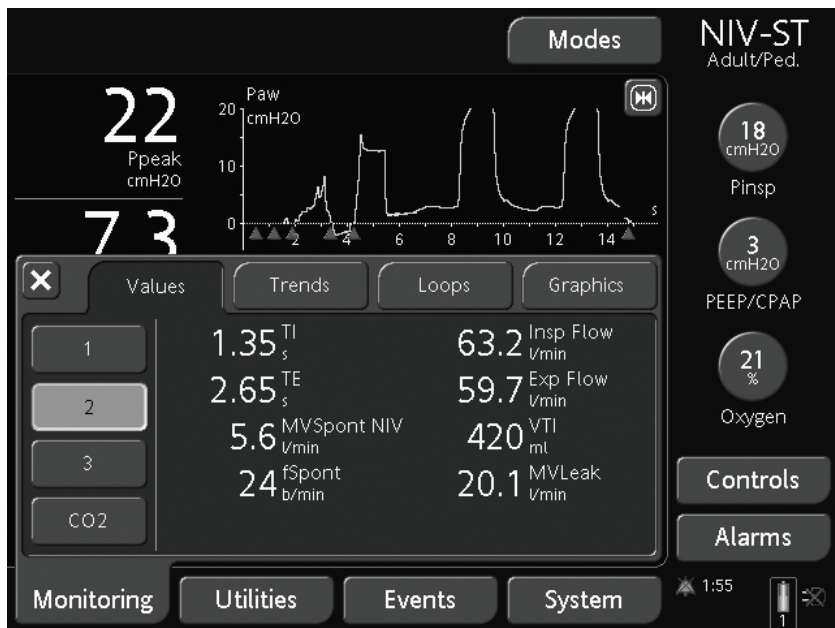


Figure 6-3. Values window 2

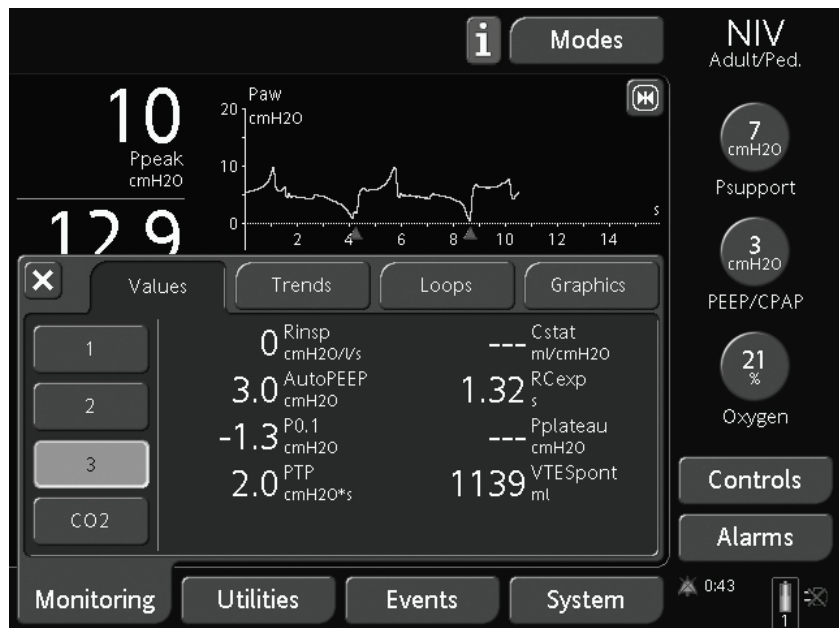


Figure 6-4. Values window 3



Figure 6-5. CO2 window

6.3 Graphics window: Selecting second screen graphic

The HAMILTON-C2 displays a pressure/time waveform by default, but through the **Graphics** window select the second graphic to be displayed at the bottom of the screen. Section 6.4 describes the graphic types.

1. Open the **Monitoring** -> **Graphics** window (Figure 6-6) either with the window tab or by touching the graphic at the bottom of the screen.
2. Select the desired type of graphic:
 - **Flow**: Flow/time waveform
 - **Volume**: Volume/time waveform
 - **Dynamic Lung**

- Vent Status
- ASV graph
- PCO₂
- FCO₂

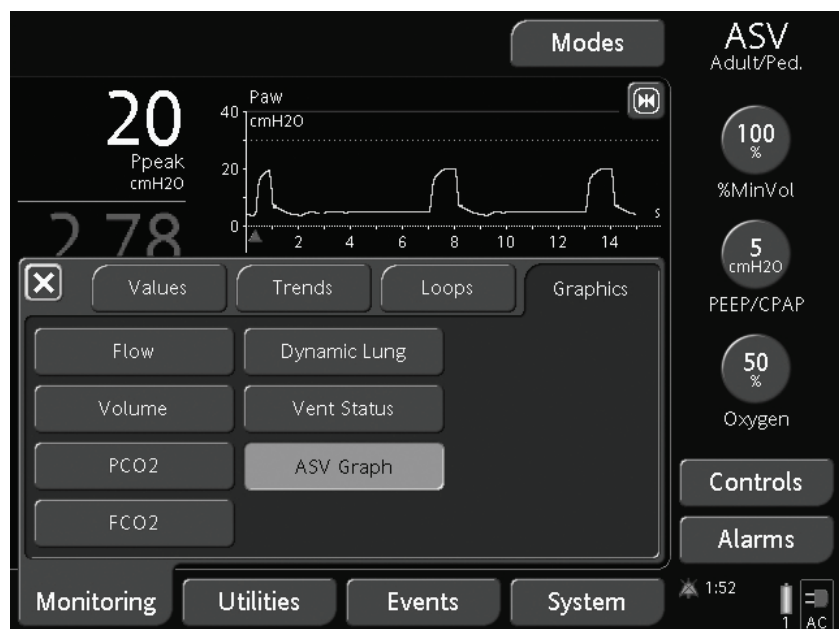


Figure 6-6. Graphics window

6.4 About graphic types

6.4.1 Waveforms

NOTE:

The ventilator uses an autoscaling function, so the scales of individual waveforms may differ, based on the range of values to be displayed. For example, the flow scale may vary from one flow/time waveform to another.

The HAMILTON-C2 plots pressure, volume, and flow against time. A blue pressure limitation line shows the maximum "safe" pressure, which is 10 cmH₂O below the set Pressure alarm limit. The Pressure limit is shown as a red line.

When the ventilator is in the (S)CMV+, or SIMV+ mode, it uses Pressure as a safety boundary for its inspiratory pressure adjustment. The ventilator does not apply inspiratory pressures higher than this pressure limitation value. An exception is sigh breaths, when the ventilator may apply inspiratory pressures 3 cmH₂O below the Pressure alarm limit.

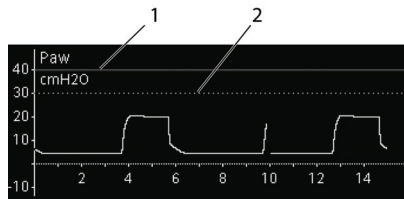


Figure 6-7. Pressure waveform display

- 1 Red Pressure alarm line
- 2 Blue Pressure limitation line

6.4.2 Dynamic Lung

The Dynamic Lung panel visualizes tidal volume, lung compliance, patient triggering, and resistance in real-time. For more information, see Section 7.2.

6.4.3 Vent Status

The Vent Status panel visualizes parameters related to oxygenation, CO₂ elimination, and patient activity, and it indicates the patient's level of ventilator dependency and when discontinuing ventilation should be considered. For more information, see Section 7.3.

6.5 Trends

Choose to show monitored parameters as 1-, 6-, 12-, or 24-hour trends. You will see the trend displays (Figure 6-8), including all data since you switched on the ventilator for the past 1, 6, 12, or 24 hours.

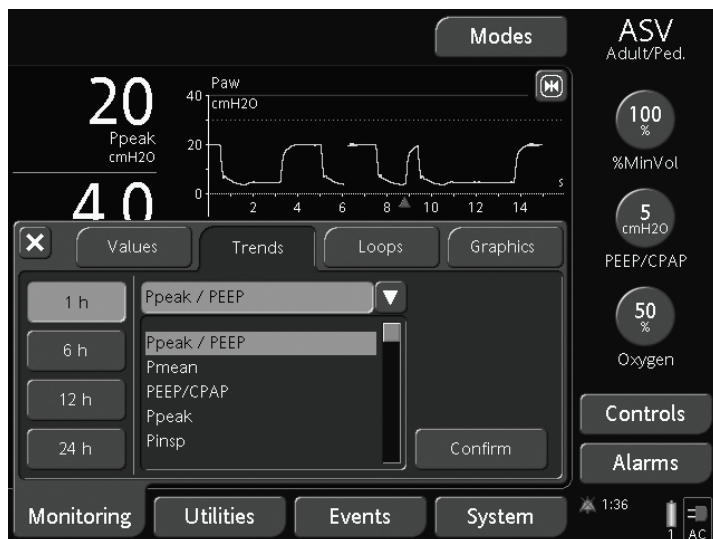


Figure 6-8. Trends window

From the time you switch on power to the HAMILTON-C2, the HAMILTON-C2 continually stores the monitored parameters in its memory, so you have access to any of this data, even after standby. If the HAMILTON-C2 is switched off, the data of the last patient appears from the memory when power is switched on again.

The freeze and cursor measurement function (Section 6.6) may also be used to examine points on trend waveforms. When trends are frozen, the time axis shows elapsed time relative to the present and the corresponding value of the monitored parameter.

All monitoring parameters can be trended. The following parameters are trended in combination:

- Ppeak/PEEP
- fTotal/fControl
- MV SPONT/ExpMinVol
- Vtal/VTE

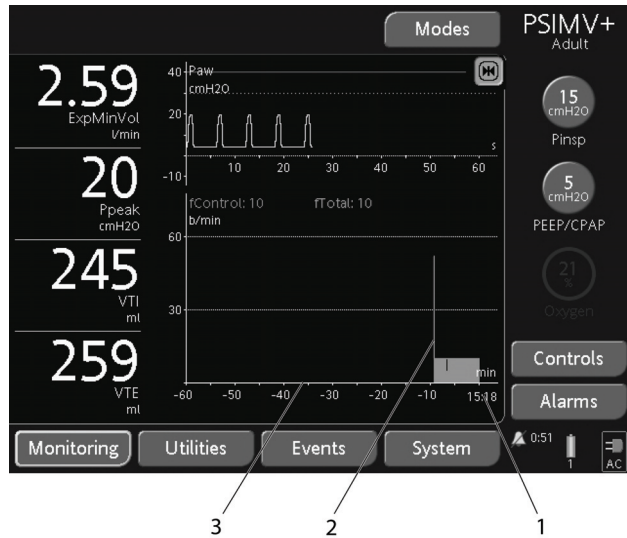


Figure 6-9. Trend display

- 1 Current time
- 2 Mean or median value (green)
- 3 Elapsed time relative to present

6.6 Loops

The Hamilton-C2 can display a dynamic loop based on the following parameter combinations (Figure 6-10):

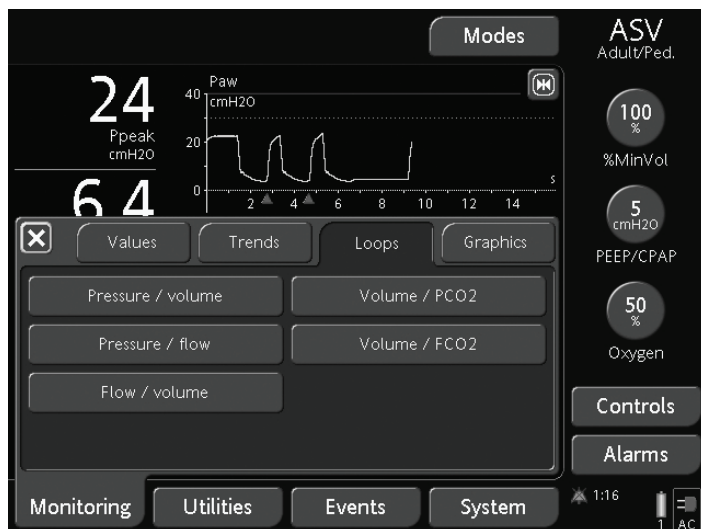


Figure 6-10. Loop window

- Pressure-Volume
- Pressure-Flow
- Flow-Volume
- Volume-PCO2
- Volume-FCO2

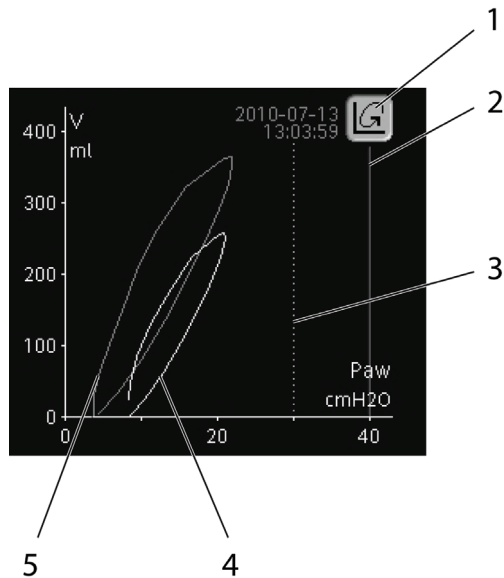


Figure 6-11. Loop display

- 1** Loop reference button
- 2** Pmax
- 3** Pressure limitation
- 4** Actual curve
- 5** Curve in the past

1. Press the loop reference button to store the loop curve with the current date and time. The past and actual characteristics are shown (Figure 6-10).

If the parameter combination is changed and the loop button is pressed again, the present curve is stored. The one before is lost.

6.7 Table of monitored parameters

NOTE:

The HAMILTON-C2 automatically measures inspiratory resistance (Rinsp), compliance (Cstat), and AutoPEEP breath by breath, during mandatory and spontaneous breaths in all modes, without interruption in ventilation. To obtain these measurements, the HAMILTON-C2 uses a statistical technique called the Least Squares Fitting (LSF) method. This method is applied on a breath-by-breath basis, without the need for special inspiratory flow patterns and occlusion maneuvers, provided that the patient is relaxed or nearly relaxed.

Actively breathing patients can create artifacts or noise, which can affect the accuracy of these measurements, however. The more active the patient, the less accurate the measurements. To minimize patient participation during these measurements, you may want to increase Psupport by 10 cmH₂O. After completion, return this control to its former setting.

Table 6-1 is an alphabetical list of the HAMILTON-C2's monitored parameters. These can be viewed in the **Values** windows (Figure 6-2 through Figure 6-4). The display of monitored parameters is updated every breath.

Table 6-1. Monitored parameters

Parameter (unit)	Definition
AutoPEEP (cmH ₂ O)	The difference between the set PEEP and the calculated total PEEP within the lungs. AutoPEEP is the abnormal pressure generated by air "trapped" in the alveoli due to inadequate lung emptying. Ideally, it should be zero. AutoPEEP is calculated using the LSF method applied to the entire breath. When AutoPEEP is present, volutrauma or barotrauma might develop. In active patients, AutoPEEP may present an extra workload to the patient. AutoPEEP or air trapping may result from an expiratory phase that is too short, which may be observed under these conditions: • Delivered tidal volume too large • Expiratory time too short or respiratory rate too high • Circuit impedance too high or expiratory airway obstruction • Peak expiratory flow too low
Cstat (ml/cmH ₂ O)	Static compliance of the respiratory system, including lung and chest wall compliances. It is calculated using the LSF method. Cstat can help diagnose changes in elastic characteristics of the patient's lungs. NOTE: Actively breathing patients can create artifact or noise, which can affect the accuracy of these measurements, however. To minimize patient participation during these measurements, you may want to increase P_{support} by 10 cmH₂O. After completion, return this control to its former setting.
Exp Flow (l/min)	Peak expiratory flow.

Table 6-1. Monitored parameters (continued)

Parameter (unit)	Definition
ExpMinVol (l/min)	Expiratory minute volume. The moving average of the monitored expiratory volume per minute over the last 8 breaths.
FetCO2 (%)	Fractional end-tidal CO2 concentration. $P_{etCO2}/(P_{\text{ambient}} - P_{H_2O})$, where $P_{H_2O} = 47$ mmHg. Permits assessment of arterial CO ₂ . (Note that it is inaccurate in pulmonary embolism.) Available if optional CO2 sensor is installed.
fControl (b/min)	Mandatory breath frequency. The moving average of machine-delivered breaths per minute over the last 8 total breaths.
fSpont (b/min)	Spontaneous breath frequency. The moving average of spontaneous breaths per minute over the last 8 total breaths. An increased fSpont may indicate that the patient is compensating for a low compliance. This may indicate ventilatory fatigue due to imposed work of breathing.
fTotal (b/min)	Total breathing frequency. The moving average of the patient's total breathing frequency over the last 8 breaths, including both mandatory and spontaneous breaths. When the patient triggers or the user initiates a breath, fTotal may be higher than the Rate setting. NOTE: Respiratory rate monitoring on the HAMILTON-C2 requires breath delivery followed by detection of expiratory flow at the proximal Flow Sensor.
I:E	Inspiratory:expiratory ratio. Ratio of the patient's inspiratory time to expiratory time for every breath cycle. This includes both mandatory and spontaneous breaths. I:E may differ from the set I:E ratio if the patient breathes spontaneously.
Insp Flow (l/min)	Peak inspiratory flow, spontaneous or mandatory.

Table 6-1. Monitored parameters (continued)

Parameter (unit)	Definition
Leak(%) / MV Leak (l/min)	Leakage percent. The percentage of the delivered inspiratory volume (VTI) that is not returned during exhalation, averaged over the past 8 breaths. Leak can indicate leaks on the patient side of the Flow Sensor (endotracheal tube, chest tube, mask). It does not include leakage between the ventilator and Flow Sensor. In non invasive modes the Leak% parameter is replaced by the MVLeak.
MVSpont/ MVSpont NIV (l/min)	Spontaneous expiratory minute volume. The moving average of the monitored expiratory volume per minute for spontaneous breaths, over the last 8 mandatory and spontaneous breaths. In non invasive ventilation modes, MVSpont is replaced by MVSpont NIV. MV Spont NIV is an adjusted parameter taking into account the leakage.
Oxygen (%)	Oxygen concentration of the delivered gas. It is measured by the oxygen cell in the inspiratory pneumatics. This parameter is not displayed if the oxygen supply is not connected; if the oxygen cell is not installed, is defective, or is not a genuine HAMILTON MEDICAL part; or if oxygen monitoring is disabled.

Table 6-1. Monitored parameters (continued)

Parameter (unit)	Definition
P0.1 (cmH ₂ O)	NOTE: Due to changes in pneumatic impedance, P0.1 values may vary with different settings of the Trigger function. Airway occlusion pressure. The maximal slope of the airway pressure drop during the first 100 ms when the airway is occluded. P0.1 indicates the patient's respiratory drive and efforts. It applies to patient-triggered breaths with pressure trigger only. A P0.1 value of -3 cmH₂O indicates a strong inspiratory effort, and a value of -5 cmH₂O, an excessive effort, possibly because the patient is "air hungry" (peak inspiratory flow or total ventilatory support is inadequate) or has an excessive drive. If P0.1 is below -3 cmH₂O... • Increase pressure or volume settings (depending on mode) • Increase %MinVol if in manual mode • Shorten P-ramp time
PEEP/CPAP (cmH ₂ O)	Monitored PEEP (positive end expiratory pressure)/CPAP (continuous positive airway pressure). The airway pressure at the end of exhalation. Measured PEEP/CPAP may differ slightly from set PEEP/CPAP, especially in actively breathing patients.
PetCO ₂ (mmHg)	End-tidal CO₂ pressure. The maximum partial pressure of CO₂ exhaled during a tidal breath (just before the start of inspiration). It represents the final portion of air that was involved in the exchange of gases in the alveolar area. Under certain conditions, it thus represents a reliable index of CO₂ partial pressure in the arterial blood. (Note that it is inaccurate in pulmonary embolism.) Available if optional CO₂ sensor is installed.

Table 6-1. Monitored parameters (continued)

Parameter (unit)	Definition
Pinsp (cmH ₂ O)	Inspiratory pressure, the automatically calculated target pressure (additional to PEEP/CPAP) applied during the inspiratory phase. Available in the Vent Status panel. Pinsp is as follows: (S)CMV+, SIMV+: Automatically calculated target pressure Pressure-controlled mode (PCV+): Pcontrol setting PSIMV+, NIV-ST, nCPAP-PS: Pinsp setting SPONT, NIV: Psupport setting APRV, DuoPAP: Phigh setting
Pmean (cmH ₂ O)	Mean airway pressure. The absolute pressure, averaged over the breath cycle. Pmean is an important indicator of the possible impact of applied positive pressure on hemodynamics and surrounding organs.
Ppeak (cmH ₂ O)	Peak airway pressure. The highest pressure during the previous breath cycle. It is influenced by airway resistance and compliance. It may differ noticeably from alveolar pressure if airway flow is high.
Pplateau (cmH ₂ O)	Plateau or end-inspiratory pressure. The pressure measured at the end of inspiration when flow is or is close to zero. Pplateau is displayed for mandatory and time-cycled breaths. Pplateau is a rough representation of alveolar pressure.

Table 6-1. Monitored parameters (continued)

Parameter (unit)	Definition
PTP (cmH ₂ O*s)	Inspiratory pressure time product. The measured pressure drop required to trigger the breath multiplied by the time interval until the PEEP/CPAP level is reached at the beginning of inspiration. ThePTP indicates work by the patient to trigger the breath. The work depends on • the intensity of the patient's effort, • the trigger type and sensitivity, and • the volume and resistance of the breathing circuit. PTP is valid for patient-initiated breaths only. The PTP does not indicate total patient work. But it is a good indicators of how well the ventilator is adapted to the patient. If PTP values increase... • Check and remove water in tubes • Switch to flow trigger • Increase trigger sensitivity

Table 6-1. Monitored parameters (continued)

Parameter (unit)	Definition
RCexp (s)	Expiratory time constant. The rate at which the lungs empty, as follows: Actual TE% emptying 1 x RCexp 63% 2 x RCexp 86.5% 3 x RCexp 95% 4 x RCexp 98% RCexp is calculated as the ratio between VTE and flow at 75% of the VTE. In adults, an RCexp value above 1.2 s indicates airway obstruction, and a value below 0.5 s indicates a severe restrictive disease. Use RCexp to set optimal TE (Goal: $TE \geq 3 \times RCexp$): • In passive patients: Adjust rate and I:E. • In active patients: Increase Psupport and/or ETS to achieve a longer TE. These actions may reduce the incidence of AutoPEEP.
Rinsp (cmH ₂ O/(l/s))	Resistance to inspiratory flow caused by the endotracheal tube and the patient's airways, during inspiration. It is calculated using the LSF method applied to the inspiratory phase. NOTE: Actively breathing patients can create artifact or noise, which can affect the accuracy of these measurements, however. To minimize patient participation during these measurements, you may want to increase Psupport by 10 cmH₂O. After completion, return this control to its former setting.
slopeCO2 (%CO ₂ /l)	Slope of the alveolar plateau. Volume/flow status of the lungs. Permits assessment of COPD, asthma and inefficient ventilation. Available if optional CO₂ mainstream sensor is installed.

Table 6-1. Monitored parameters (continued)

Parameter (unit)	Definition
TE (s)	Expiratory time. In mandatory breaths, TE is measured from the start of exhalation until the set time has elapsed for the switchover to inspiration. In spontaneous breaths, TE is measured from the start of exhalation, as dictated by the ETS setting, until the patient triggers the next inspiration. TE may differ from the set expiratory time if the patient breathes spontaneously.
TI (s)	Inspiratory time. In mandatory breaths, TI is measured from the start of breath delivery until the set time has elapsed for the switchover to exhalation. In spontaneous breaths, TI is measured from the patient trigger until the flow falls to the ETS setting, for the switchover to exhalation. TI may differ from the set inspiratory time if the patient breathes spontaneously.
V'alv (ml/min)	Alveolar minute ventilation. $\text{Valv} \times f$ (normalized to 1 min). Permits assessment of actual alveolar ventilation (as opposed to minute ventilation). Available if optional CO ₂ mainstream sensor is installed.
V'CO ₂ (ml/min)	CO ₂ elimination. Net exhaled volume of CO ₂ per minute. Permits assessment of metabolic rate (e.g., it is high with sepsis, tetanus, etc.) and treatment progress. Available if optional CO ₂ mainstream sensor is installed.
VDaw (ml)	Airway dead space. Gives an effective, in-vivo measure of volume lost in the conducting airways. A relative increase in dead space points to a rise in respiratory insufficiency and can be regarded as an indicator of the current patient situation. Patients with high dead space values are at particular risk if the muscles then also show signs of fatigue. Available if optional CO ₂ mainstream sensor is installed.
VDaw/VTE (%)	Airway dead space fraction at the airway opening. Available if optional CO ₂ mainstream sensor is installed.
VeCO ₂ (ml)	Exhaled CO ₂ volume. Updated breath by breath. Available if optional CO ₂ mainstream sensor is installed.

Table 6-1. Monitored parameters (continued)

Parameter (unit)	Definition
ViCO2 (ml)	Inspired CO ₂ volume. Updated breath by breath. Available if optional CO ₂ mainstream sensor is installed.
Vtalv (ml)	Alveolar tidal ventilation. VTE - VDaw. Available if optional CO ₂ mainstream sensor is installed.
VTE/VTE NIV (ml)	Expiratory tidal volume. The volume exhaled by the patient. It is determined from the Flow Sensor measurement, so it does not show any volume added due to compression or lost due to leaks in the breathing circuit. If there is a gas leak at patient side, the displayed VTE may be less than the tidal volume the patient actually receives. In non invasive ventilation modes, VTE is replaced by VTE NIV. VTE NIV is an adjusted parameter taking into account the leakage
VTEspont (ml)	Spontaneous expiratory tidal volume. The volume exhaled by the patient. If there is a gas leak at patient side, the displayed VTEspont may be less than the tidal volume the patient actually receives. Only displayed for spontaneous breaths.
VTI (ml)	Inspiratory tidal volume. The volume delivered to the patient. It is determined from the Flow Sensor measurement. If there is a gas leak at the patient side, the displayed VTI may be larger than the displayed VTE.

6.8 Freeze and cursor measurement

NOTE:

The graphic is frozen for 30 seconds.

This function lets you freeze the display of a graphic.

The freeze function is particularly useful when you perform a breath hold maneuver. The screen automatically freezes following a successful inspiratory maneuver.

Freeze the graphic as follows:

1. Select the freeze button in the right upper corner. This freezes the graphic (Figure 6-12).

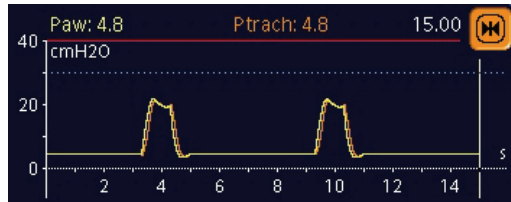


Figure 6-12. Freeze function

2. To analyze the curves turn the knob.
3. Unfreeze with the freeze button or by pressing the knob.

7 Intelligent Panels

7.1	Introduction	7-2
7.2	Dynamic Lung panel	7-2
7.2.1	Tidal volume (Vt)	7-3
7.2.2	Compliance (Cstat)	7-3
7.2.3	Patient triggering: Muscle	7-3
7.2.4	Resistance: Bronchial tree	7-4
7.3	Vent Status panel	7-5

7.1 Introduction

Lay out the ventilator screen to display any of the three types of Intelligent Panel, which are described in the following subsections.

7.2 Dynamic Lung panel

NOTE:

The dynamic lung panel is not available for neonates.

The Dynamic Lung panel (Figure 7-1) visualizes tidal volume, lung compliance, patient triggering, and resistance in real-time. The lungs expand and contract in synchrony with actual breaths. Numeric values for resistance (R_{insp}) and compliance (C_{stat}) are also displayed. If all values are in a normal range, the panel is framed in green.

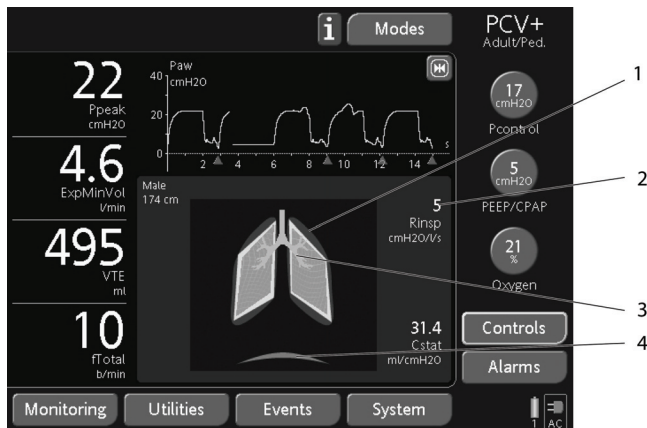


Figure 7-1. Dynamic Lung panel

- 1 "Normal" lungs (reference)
- 2 Resistance of the lung
- 3 Compliance of the lung
- 4 Patient trigger

7.2.1 Tidal volume (Vt)

The Dynamic Lung expands and contracts to show tidal volume (Vt) in real-time. It moves in synchrony with actual breaths, based on the proximal Flow Sensor signal. The lung size shown is relative to "normal" size for the patient's height (IBW), based on a "normal" value of 10 ml/kg.

A disconnection alarm is visualized by a deflated lung. An **Exhalation obstructed** alarm is visualized by an inflated lung.

7.2.2 Compliance (Cstat)

The Dynamic Lung shows compliance (Cstat) breath by breath relative to "normal" values for the patient's height (Figure 7-2). As the figure shows, the shape of the lungs changes with compliance. The numeric value is also displayed.



Figure 7-2. Compliance shown by the Dynamic Lung

7.2.3 Patient triggering: Muscle

The muscle in the Dynamic Lung shows patient triggering (Figure 7-3).

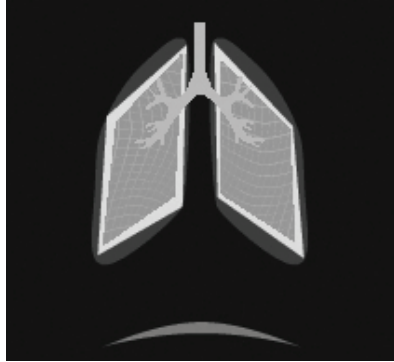


Figure 7-3. Patient triggering shown by the Dynamic Lung muscle

7.2.4 Resistance: Bronchial tree

The bronchial tree in the Dynamic Lung shows resistance (Rinsp) breath by breath relative to "normal" values for the patient's height (Figure 7-4). The numeric value is also displayed.

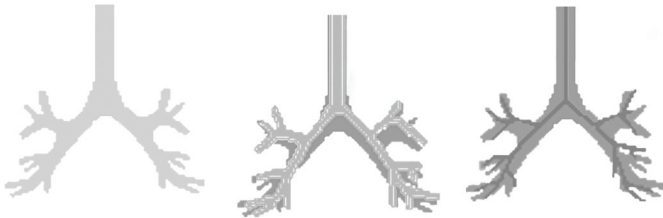


Figure 7-4. Rinsp shown by the bronchial tree of the Dynamic Lung

Table 7-1. Dynamic Lung normal values

Parameter	Definition of normal value
Tidal volume (Vt)	10 ml/kg IBW (calculated from Pat. height)
Compliance (Cstat)	For Pat. height between 30 and 135 cm (11 and 53 in.): $0.000395 * \text{Pat. height}^2.38$ For Pat. height > 135 cm (53 in.): $-0.0028 * \text{Pat. height}^2 + 1.3493 * \text{Pat. height} - 84.268$
Resistance (Rinsp)	For Pat. height $\leq$ 210 cm (83 in.): $(1.993 - 0.0092 * \text{Pat. height}) * 10.2 + 5$ For Pat. height > 210 cm (83 in.): $0.5 + 5$

7.3 Vent Status panel

The Vent Status panel (Figure 7-5) displays six parameters related to the patient's ventilator dependency, including oxygenation, CO2 elimination, and patient activity. A floating indicator (floater) moving up and down within the column shows the value for a given parameter. When the indicator is in the light blue (weaning) zone, a timer starts, showing how long that value has been in the weaning zone. When all values are in the weaning zone, the Vent Status panel is framed in green, indicating that weaning should be considered. The panel is updated breath by breath.

Table 7-2 describes the parameters shown in the Vent Status panel. You can configure the weaning zone ranges in the configuration mode. Table A-14 lists the weaning zone ranges and defaults.

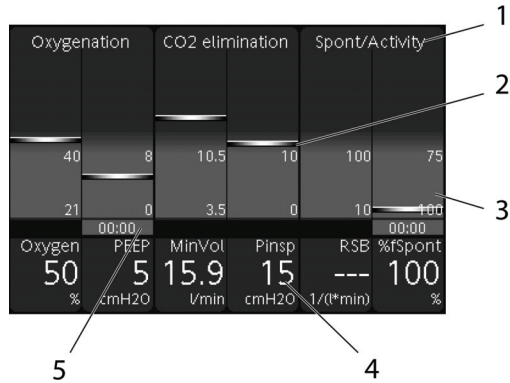


Figure 7-5. Vent Status panel

- 1 Group title
- 2 Monitored graphic value (floater)
- 3 Light blue weaning zone with user-configurable limits
- 4 Numeric monitored value
- 5 Elapsed time value has been in weaning zone

Table 7-2. Vent Status parameters

Parameter (unit)	Definition
Oxygen (%)	Oxygen setting. See Table 4-3.
PEEP (cmH ₂ O)	PEEP/CPAP setting. See Table 4-3.
MinVol (l/min)	Normal minute ventilation (defined in Appendix C).
Pinsp (cmH ₂ O)	Inspiratory pressure, the target pressure (additional to PEEP/CPAP) applied during the inspiratory phase (see Table 6-1).

Table 7-2. Vent Status parameters (continued)

Parameter (unit)	Definition
RSB (1/(l*min)) ¹	Rapid shallow breathing index. The total breathing frequency (fTotal) divided by the exhaled tidal volume (VTE). Because a patient with dyspnea typically takes faster, shallower breaths than a non-dyspnoeic patient, RSB is high in the dyspnoeic patient and low in the non-dyspnoeic patient. RSB is often used clinically as an indicator to judge whether a ventilated patient is ready for weaning. RSB has significance for spontaneously breathing patients only and is shown only if 80% of the last 25 breaths are spontaneous.
%fSpont (%)	Spontaneous breath percentage. The moving average of the percentage of spontaneous breaths over the last 8 total breaths.

1. Weaning zone defaults are based on a normal of < 100/(l*min) for adult patients.

8 Responding to alarms

8.1	Introduction	8-2
8.2	How to respond to an alarm	8-6
8.3	Alarm buffer	8-7
8.4	Events window: Reviewing the event log	8-9
8.5	Alarm troubleshooting table	8-10

8.1 Introduction

The HAMILTON-C2's alarms notify the operator of problems. These alarm types, including their audiovisual characteristics and required actions, are summarized in Table 8-1. You can view active or inactive alarms, as applicable, in the alarm buffer (Figure 8-4). Information about the alarm is also stored in an event log.

When a low-, medium-, or high-priority alarm occurs, ventilation typically continues. When the condition that caused the alarm is corrected, the HAMILTON-C2 automatically resets the alarm.

By contrast, a technical fault alarm indicates a potentially more serious equipment problem. In less serious cases, the ventilator enters the safety ventilation mode, which ensures a basic minute ventilation while giving the user time for corrective actions. A constant blower speed helps maintain the default inspiratory pressure. The expiratory valve opens as needed to switch system pressure levels between PEEP and inspiratory pressure. Patient sensing is nonfunctional during safety ventilation. You must switch off ventilator power to exit safety ventilation.

If the technical fault alarm is serious enough to possibly compromise safe ventilation, the ventilator enters the ambient state. The inspiratory valve is closed and the ambient and expiratory valves are opened, letting the patient breathe room air unassisted. You must switch off ventilator power to exit the ambient state.

Table 8-1. Alarm indications in HAMILTON-C2

Alarm type	Message bar ¹	Alarm lamp	Audio	Action required
High-priority alarm	Red, with alarm message	Red	A sequence of 5 beeps, repeated until the alarm is reset. If the audible alarm is not silenced during the first minute, the continuous-tone buzzer also sounds.	The patient's safety is compromised. The problem needs immediate attention.
Medium-priority alarm	Yellow, with alarm message	Yellow	A sequence of 3 beeps, repeated periodically. If the audible alarm is not silenced during the first minute, the continuous-tone buzzer also sounds.	The patient needs prompt attention.
Low-priority alarm	Yellow, with alarm message	Yellow	Two sequences of beeps. This is not repeated.	Operator awareness is required.
Technical fault	Red, with Safetyventilation:xxxxxx (Figure 8-2) or Technical-fault:xxxxxx (Figure 8-3)	Red	Same as for high-priority alarm, if technically possible. At the minimum a continuous buzzer tone. The buzzer cannot be silenced.	The ventilator enters the safety mode, or, if it cannot safely ventilate, the ambient state. Provide alternative ventilation. Turn off the ventilator. Have the ventilator serviced.

1. If more than one alarm is active, the associated alarm messages alternate in the message bar.

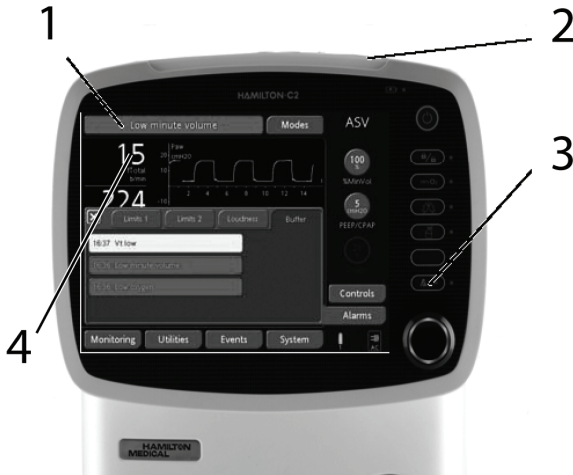


Figure 8-1. Visual alarm indications

- 1 Message bar
- 2 Alarm lamp
- 3 Alarm silence key
- 4 Monitoring parameter changing the colour during active alarm

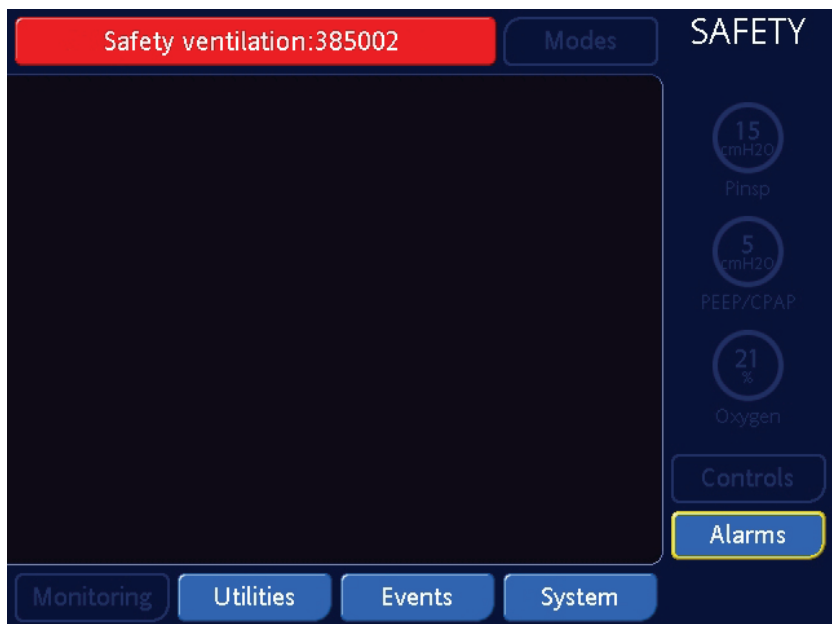


Figure 8-2. Safety ventilation screen



Figure 8-3. Ambient state

8.2 How to respond to an alarm

WARNING

- To prevent possible patient injury when alarms are active, check the patient for adequate ventilation. Identify and remove the cause of the alarms. Readjust the alarm limits only when they are inappropriately set for the current conditions.
- To prevent possible patient injury arising from an equipment malfunction, HAMILTON MEDICAL recommends that you immediately remove any ventilator with a technical fault from use, record the technical fault code, and have the ventilator serviced.

NOTE:

- Be aware that an alarm may result from either a clinical condition or an equipment problem.
 - Be aware that one alarm condition can induce multiple alarms. Normally only one or two indicate the root cause of the alarm; the rest are resultant. Your search for the causes of the alarm condition should be assisted by, but not limited to, the alarm messages displayed.
-

Respond to an alarm as follows:

1. Approach the patient immediately. Secure sufficient and effective ventilation for the patient. You may silence the alarm if possible.
2. Correct the alarm condition from the alarm messages, referring to Table 8-2. For low-, medium-, and high-priority alarms, when the alarm triggering condition is corrected, the ventilator automatically resets the alarm. For a technical fault alarm, switch off ventilator power first; then correct the problem.

8.3 Alarm buffer

The alarm buffers show up to six alarm messages:

- If there are currently active alarms, the alarm buffer shows the most recent active alarms (Figure 8-4). The associated alarm messages also alternate in the message bar. Active alarms are in boxes with rounded corners.
- If no alarms are active, the alarm buffer shows the most recent inactive alarms (Figure 8-5). Inactive alarms are in boxes with square corners.

Open the **Alarms** -> **Buffer** window with the **Buffer** tab, by touching the message bar in the upper left-hand corner, or by touching the inactive alarm indicator (Figure 8-5). The most recent alarm is at the top. You can clear the alarm messages for all inactive alarms with the **Reset** button. Closing the buffer does not erase its contents.

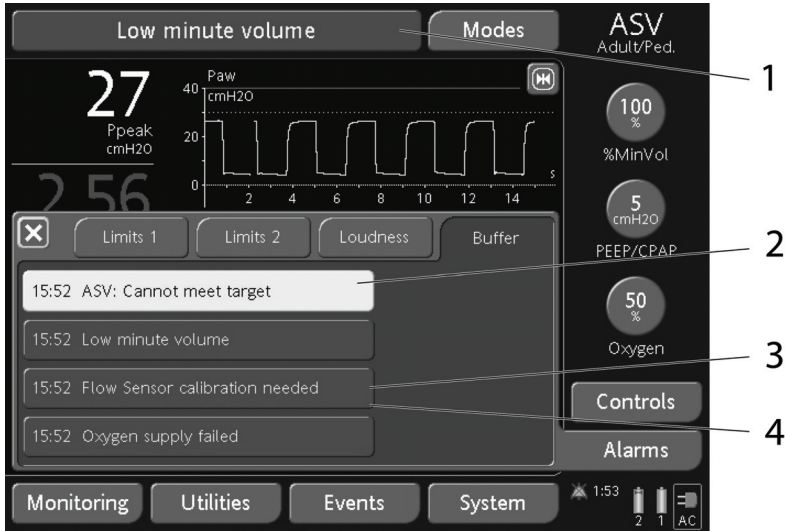


Figure 8-4. Alarm buffer with active alarms

- 1 Active alarms alternate in message bar. Touch to open alarm buffer.
- 2 Low- or medium-priority alarm (yellow background)
- 3 High-priority alarm (red background)
- 4 Box with rounded corners

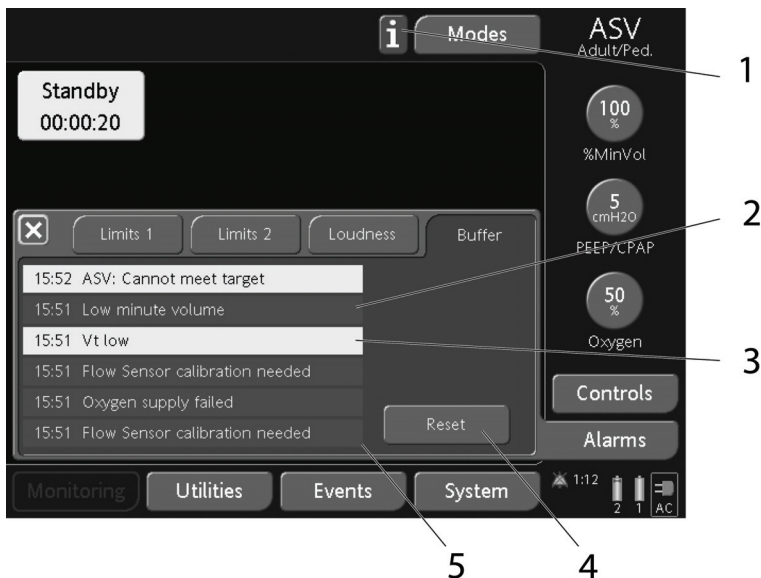


Figure 8-5. Alarm buffer with inactive alarms

- 1 Indicates there is information about inactive alarms in the alarm buffer.
- 2 High-priority alarm (red background)
- 3 Low- or medium-priority alarm (yellow background)
- 4 **Press Reset** button to clear information about inactive alarms
- 5 Box with square corners

8.4 Events window: Reviewing the event log

The **Events** window shows the event log, or data about clinically relevant ventilator occurrences since the HAMILTON-C2 was powered on, including alarms, setting changes, calibrations, maneuvers, and special functions. The date, time, and description are included.

NOTE:

A more extensive log including technical and configuration information is available to service engineers.

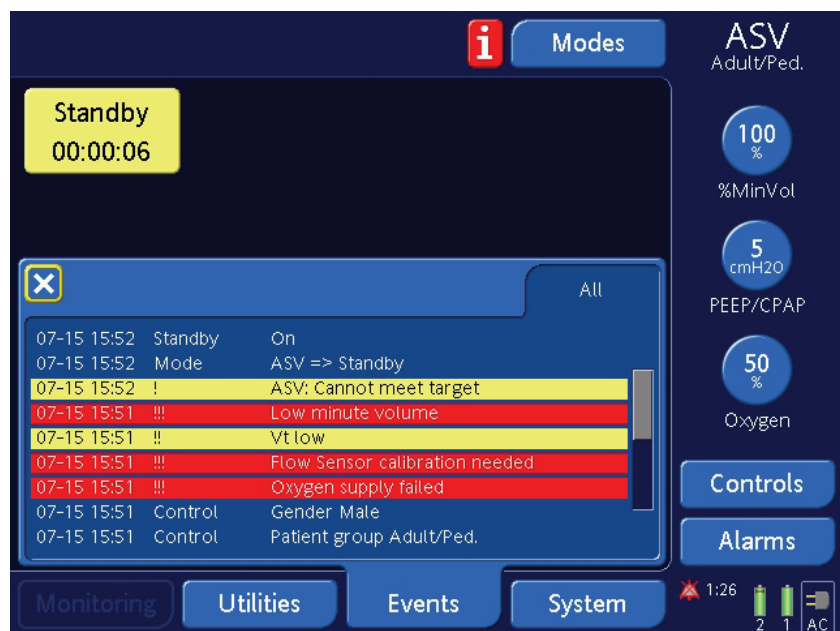


Figure 8-6. Events window

8.5 Alarm troubleshooting table

Table 8-2 is an alphabetical list of the alarm messages displayed by the HAMILTON-C2, along with their definitions and suggested corrective actions. These corrective actions are sequenced to correct the most probable malfunction or to present the most efficient corrective action first. The proposed actions, however, may not always correct the particular problem.

Table 8-2. Alarms and other messages

Alarm	Definition	Action needed
Air supply	<i>High priority.</i> The turbine is not delivering sufficient flow. The ventilator ventilates the patient with the available flow.	Service personnel needed
Apnea	<i>High priority.</i> No patient trigger within the operator-set Apnea time in SPONT, SIMV+, or NIV mode.	Check the patient. Consider switching to a mandatory mode or increasing the mandatory rate.
Apnea ventilation	<i>Low priority.</i> No breath delivered for the operator-set apnea time. Apnea backup is on.	Apnea backup ventilation has started. The ventilator is in the corresponding backup mode. Check the control settings for the backup mode.
Apnea ventilation ended	<i>Low priority.</i> Backup mode was reset, and HAMILTON-C2 is again ventilating in its original support (pre-apnea) mode.	No action required.
ASV: Can-not meet the target	<i>Low priority.</i> The operator-set %MinVol cannot be delivered, possibly because of setting conflicts.	Check maximum pressure in alarm setting.
Battery 1 calibration required	<i>Low priority.</i> Battery 1 requires calibration. You may continue to use the battery.	Calibrate the battery.
Battery 2 calibration required	<i>Low priority.</i> Battery 2 requires calibration. You may continue to use the battery.	Calibrate the battery.
Battery low	<i>High priority.</i> The ventilator is running on its battery, and the battery can support < 10 min ventilator operation.	Connect the ventilator to its primary power source. Install charged batteries.

Table 8-2. Alarms and other messages

Alarm	Definition	Action needed
Battery 1: temperature high	<i>High priority.</i> The battery temperature is higher than expected.	Remove the ventilator from the sun or other heat source. Install a new battery.
Battery 2: temperature high	<i>High priority.</i> The battery temperature is higher than expected.	Remove the ventilator from the sun or other heat source. Install a new battery.
Battery power loss	<i>High priority.</i> No battery is present.	Insert a battery.
Battery 1: Wrong battery	<i>Low priority.</i> The battery in use is not a HAMILTON-C2 Li-Ion battery.	Change the battery. Use a HAMILTON-C2 Li-Ion battery.
Battery 2: Wrong battery	<i>Low priority.</i> The battery in use is not a HAMILTON-C2 Li-Ion battery.	Change the battery. Use a HAMILTON-C2 Li-Ion battery.
Check Flow Sensor	<i>High priority.</i> Flow Sensor measurements are out of expected range. The ventilator switches over to PCV+ mode and displays ventilator pressure (Pvent) instead of Paw. The ventilator automatically returns to its previous mode when the measurements are within the expected range.	Check the Flow Sensor and the sensing lines. Try to calibrate the Flow Sensor. Install a new Flow Sensor.
Check Flow Sensor tubing	<i>High priority.</i> The Flow Sensor sensing lines are disconnected or occluded. The ventilator switches over to PCV+ mode and displays ventilator pressure (Pvent) instead of Paw. The ventilator automatically returns to its previous mode when the measurements are within the expected range.	Check the Flow Sensor and the sensing lines. Try to calibrate the Flow Sensor. Install a new Flow Sensor.

Table 8-2. Alarms and other messages

Alarm	Definition	Action needed
CO ₂ calibration needed	<i>Low priority.</i> A previous sensor calibration failed.	Check adapter and clean if necessary. Then calibrate sensor, making sure there is no source of CO ₂ near the airway adapter. Recalibrate if problem persists. Install new airway adapter. Install new CO ₂ sensor.
CO ₂ sensor disconnected	<i>Low priority.</i> The CO ₂ module is installed, but there is no signal from the CO ₂ sensor. CO ₂ monitoring is enabled.	Make sure a CO ₂ sensor is installed. Check CO ₂ sensor connections (CO ₂ sensor cable to module, CO ₂ module to ventilator). Have the ventilator serviced.
CO ₂ sensor defect	<i>Low priority.</i> CO ₂ sensor signal indicates a hardware error; or a third-party sensor is installed.	Disconnect the sensor from the CO ₂ module. Wait a few seconds, and reconnect. Recalibrate the sensor. Install a new CO ₂ sensor. Make sure the sensor is a genuine HAMILTON MEDICAL part.
CO ₂ sensor over temperature	<i>Low priority.</i> Temperature at CO ₂ sensor too high.	Remove the sensor from the airway, and disconnect the sensor from the CO ₂ module. Reconnect. Verify that system is running within the specified environmental conditions. Check for excessive airway temperature (e.g., caused by defective humidifier, heater wire, or probe).

Table 8-2. Alarms and other messages

Alarm	Definition	Action needed
Device temperature high	<i>High priority.</i> The internal temperature of the ventilator is higher than expected.	Remove the ventilator from the sun or other heat source. Check the cooling fan filter and fan. Have the ventilator serviced.
Disconnection	<i>High priority.</i> Peak pressure lower than expected in NIV or NIV-ST mode.	Troubleshoot as per Disconnection on patient side or Disconnection on ventilator side alarm.
Disconnection on patient side	<i>High priority.</i> VTE < 1/8 delivered VTI, and delivered VTI > 50 ml.	Check the patient. Check the breathing circuit for a disconnection between the patient and the Flow Sensor, or for other large leaks (for example, ET tube, bronchopleural fistula).
Disconnection on ventilator side	<i>High priority.</i> VTI measured at the airway < 1/2 delivered VTI, and delivered VTI > 50 ml.	Check the breathing circuit for a disconnection between the ventilator and the Flow Sensor or for other large leaks (for example, breathing circuit, humidifier). Reconnect and calibrate the Flow Sensor.
Exhalation obstructed	<i>High priority.</i> End-expiratory pressure $\geq$ (set PEEP/CPAP + 5 cmH ₂ O).	Check the patient. Check the expiratory limb for occlusion. Check the expiratory valve membrane and cover. Check the Flow Sensor tubes for occlusion. Adjust breath timing controls to increase the expiratory time. Have the ventilator serviced.

Table 8-2. Alarms and other messages

Alarm	Definition	Action needed
Exhalation port occluded	<i>High priority.</i> The baseline circuit flow is < 3 l/min for a period of 1 min. Active only in NIV, NIV-ST and nCPAP-PS.	Check the LiteCircuit for leakage.
External Flow Sensor failed	<i>High priority.</i> The external flow sensor doesn't work properly.	Change the flow sensor.
Fan failure	<i>Medium priority.</i> The cooling fan is malfunctioning.	Disconnect the ventilator from the patient. Have the ventilator serviced. CAUTION A fan failure could result in oxygen enrichment inside the ventilator and a subsequent fire hazard.
High frequency	<i>Medium priority.</i> The measured f_{Total} > the set alarm limit.	Check the patient for adequate ventilation (VTE). Check the alarm limits. If the ventilator is in ASV, refer to Appendix C-2.
High minute volume	<i>High priority.</i> The measured ExpMinVol > the set alarm limit.	Check the patient. Check and adjust the ventilator settings, including alarms.
High oxygen	<i>High priority.</i> Measured Oxygen is > the set alarm limit (low-pressure oxygen) or the operator-set Oxygen + 5% (high-pressure oxygen).	Calibrate the oxygen cell. Install a new oxygen cell.
PetCO ₂ high	<i>Medium priority.</i> PetCO ₂ > the set alarm limit.	Check the patient. Check and adjust the ventilator settings, including alarms.

Table 8-2. Alarms and other messages

Alarm	Definition	Action needed
High pressure	<i>High priority.</i> The measured inspiratory pressure > the set Pressure alarm limit. The ventilator immediately closes the inspiratory valve to stop gas flow to the patient and opens the expiratory valve to reduce pressure to the PEEP/CPAP level. The ventilator attempts to limit patient airway pressure to 60 cmH ₂ O, but if pressure climbs to 75 cmH ₂ O, the ventilator enters the ambient state. This alarm cannot be silenced.	Check the patient. Adjust the Pressure alarm limit. Check the breathing circuit and Flow Sensor tubes for kinks and occlusions. Provide alternative ventilation once the ventilator enters the ambient state.
High pressure during sigh	<i>Low priority.</i> A sigh cannot be fully delivered, because excessive inspiratory pressure (Pressure -3 cmH ₂ O) would be required. The sigh is partially delivered.	Check the patient. Check the breathing circuit. Adjust the Pressure alarm limit. Consider disabling the sigh function.
Instrument maybe contaminated	<i>Low priority.</i> It is possible that the HAMILTON-C2 has been contaminated.	Decontaminate the instrument.
IRV	<i>Low priority.</i> The set I:E ratio is above 1:1, leading to inverse ratio ventilation.	Check the timing control settings.
Loss of external power	<i>High priority, reset when silenced.</i> The HAMILTON-C2 is running on battery power due to loss of its primary power source.	Silence the alarm. Check integrity of connection to primary power source. Check battery status. If you have spare batteries, prepare to swap if necessary. Prepare for possible power loss. Obtain alternative ventilation.

Table 8-2. Alarms and other messages

Alarm	Definition	Action needed
Loss of PEEP	<i>Medium priority.</i> Paw < (PEEP/CPAP - 3 cmH ₂ O) for more than 10 s and PEEP/CPAP ³ 4 cmH ₂ O.	Check the patient. Check the breathing circuit for leaks. Replace the breathing circuit, if necessary.
Low frequency	<i>Medium priority.</i> Measured fTotal < the set alarm limit.	Check the patient. Adjust the low fTotal alarm limit. If the ventilator is in ASV, check the %MinVol and Pat. height settings. Consider suctioning, check for a kinked ET tube, or consider the possibility of acute asthma.
Low minute volume	<i>High priority.</i> Measured ExpMinVol < the set alarm limit.	Check the patient. Check the breathing circuit. Check and adjust the ventilator settings, including alarms. If the ventilator is in ASV, check the %MinVol and Pat. height settings. Consider suctioning, check for a kinked ET tube, or consider the possibility of acute asthma.
Low oxygen	<i>High priority.</i> Measured Oxygen is < the set alarm limit (low-pressure oxygen) or the operator-set Oxygen - 5% (high-pressure oxygen).	Check the patient. Check the oxygen supply. Provide an alternative source of oxygen, if necessary. Calibrate the oxygen cell. Install a new oxygen cell.
PetCO ₂ low	<i>Medium priority.</i> PetCO ₂ < the set alarm limit.	Check the patient. Check and adjust the ventilator settings, including alarms.

Table 8-2. Alarms and other messages

Alarm	Definition	Action needed
Low pressure	<i>High priority.</i> Set pressure during inspiration not reached.	Check the patient. Check the breathing circuit for a disconnection between the patient and the Flow Sensor, or for other large leaks (for example, ET tube, bronchopleural fistula).
O2 cell calibration needed	<i>Low priority.</i> Oxygen cell calibration data is not within expected range, or cell is new and requires calibration.	Calibrate the oxygen cell.
O2 cell defective	<i>High priority.</i> The oxygen cell is depleted.	Install a new oxygen cell.
CAUTION To ensure that oxygen monitoring is always fully functional, replace an exhausted or missing oxygen cell as soon as possible or use an external monitor that complies with ISO 21647.		
O2 cell missing	<i>Low priority.</i> There is no signal from the oxygen cell.	Install an oxygen cell or use an external monitor, according to ISO 21647.
CAUTION To ensure that oxygen monitoring is always fully functional, replace an exhausted or missing oxygen cell as soon as possible or use an external monitor that complies with ISO 21647.		
NOTE: To prevent leakage within the ventilator, make sure an oxygen cell is installed at all times, even if you use an external monitor or disable oxygen monitoring.		

Table 8-2. Alarms and other messages

Alarm	Definition	Action needed
O2 cell not system-compatible	<i>Low priority.</i> The incorrect type of oxygen cell is installed.	Install an oxygen cell intended for the HAMILTON-C2 (PN 396200).
Oxygen supply failed	<i>High priority.</i> Oxygen source flow lower than expected.	Check the patient. Check the oxygen supply. Provide an alternative source of oxygen, if necessary.
Pressure limit has changed	<i>Low priority.</i> You have changed either the Pressure or Psvlimit in ASV. Changing either setting automatically changes the other: Pressure is always 10 cmH ₂ O greater than Psvlimit.	Make sure the pressure limit is high enough so that sufficient pressure can be applied for adequate breath delivery.
Pressure limitation	<i>Medium priority at first, then low priority after silenced.</i> Inspiratory pressure, including PEEP/CPAP, is 10 cmH ₂ O below Pressure. The ventilator limits applied pressure, so the target pressure or volume may not be achieved.	Check the patient for adequate ventilation. Check ventilator settings and alarm limits.
Pressure not released	<i>High priority.</i> Airway pressure has exceeded the Pressure limit, and the pressure was not released via the expiratory valve after 5 s. The ventilator enters the ambient state.	Provide alternative ventilation. Check expiratory valve and breathing circuit. Have the ventilator serviced.
Preventive maintenance required	<i>Low priority.</i> According to its operating hours, the ventilator requires preventive maintenance.	Have the ventilator serviced.
Replace HEPA filter	<i>Low priority.</i> The air inlet HEPA filter shows increased resistance.	Replace the HEPA filter.

Table 8-2. Alarms and other messages

Alarm	Definition	Action needed
Real time clock failure	Low priority. Date and time not set.	Set date and time.
Safety ventilation: xxxxxx	<i>Technical fault.</i> A hardware or software malfunction was detected. The ventilator switches to the safety mode. CAUTION To prevent possible patient injury arising from an equipment malfunction, HAMILTON MEDICAL recommends that you immediately remove any ventilator with a technical fault from use, record the code, and have the ventilator serviced.	Provide alternative ventilation. Have the ventilator serviced.
Technical event: xxxxxx	<i>Low, medium, or high priority.</i> A hardware or software malfunction was detected. A technical alarm cannot typically be corrected by the operator. Ventilation continues.	Have the ventilator serviced.
Technical fault: xxxxxx	<i>Technical fault.</i> A hardware or software malfunction was detected. The ventilator switches to the ambient state. CAUTION To prevent possible patient injury arising from an equipment malfunction, HAMILTON MEDICAL recommends that you immediately remove any ventilator with a technical fault from use, record the code, and have the ventilator serviced.	Provide alternative ventilation. Have the ventilator serviced.

Table 8-2. Alarms and other messages

Alarm	Definition	Action needed
Turn Flow Sensor	<i>Low priority.</i> The Flow Sensor connections are reversed. Ventilation continues, but the ventilator corrects for the reversed signal.	Reverse the ends of the Flow Sensor. The blue sensing line is close to the patient and must be attached to the blue connector. The colorless sensing line is close to the ventilator and must be attached to the white connector.
Vt high	<i>Medium priority.</i> The delivered Vt > 1.5 the set Vt high alarm limit. Pressure is reduced by 3 mbar for next breath.	Reduce the Psupport setting. Adjust the high Vt high alarm limit.
Vt outlet temperature high	<i>High priority.</i> Measured inhalation temperature is too high.	Check if the room temperature is exceeding temperature of operation. Have the ventilator serviced if temperature can not be reduced.
Vt low	<i>Medium priority.</i> Measured VTE < the set limit for 2 consecutive breaths.	Check the patient. Check and adjust the ventilator settings, including alarm limits. Check for leaks and disconnects. If the ventilator is in ASV, consider suctioning, check for a kinked ET tube, or consider the possibility of acute asthma.
Wrong flow sensor	<i>High priority.</i> The type of flow sensor installed (adult or infant) does not match the patient type setting.	Take the appropriate flow sensor. Calibrate again.

9 Special functions

9.1	Standby	9-2
9.2	O2 enrichment	9-5
9.3	Suctioning tool	9-6
9.4	Manual breath/inspiratory hold	9-7
9.5	Nebulizer	9-8
9.6	Print screen	9-9

9.1 Standby

WARNING

- To prevent possible patient injury due to lack of ventilatory support, secure alternative ventilation for the patient before entering the standby mode. You must confirm that no patient is attached before entering standby.
 - To prevent possible patient injury or damage to breathing circuit from overheated gas after reconnection from standby, turn off the humidifier when entering the standby mode.
-

NOTE:

- To keep the batteries fully charged, make sure the ventilator is connected to AC power while in standby mode.
 - When in standby, the HAMILTON-C2 does not automatically resume ventilation when the patient is reconnected. Instead you must manually restart ventilation.
 - Patient alarms are suppressed during standby.
 - Acustical patient alarms are suppressed 1 minute after starting ventilation from standby.
-

Standby is a waiting mode that lets you maintain ventilator settings while the HAMILTON-C2 is not performing any ventilatory functions.

To put the ventilator into standby, press and quickly release the power/standby switch (Figure 9-1) while the ventilator is powered on. The **Activate standby** window (Figure 9-2) opens. Select **Activate standby**.

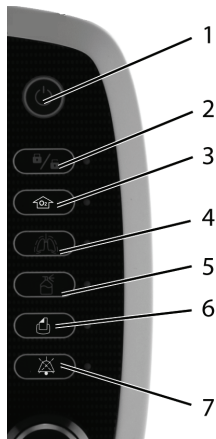


Figure 9-1. Special function keys

- 1** Power/standby switch
- 2** Screen lock/ unlock
- 3** O2 enrichment/ suctioning
- 4** Manual breath/inspiratory hold
- 5** Nebulizer on/off
- 6** Print screen
- 7** Alarm silence

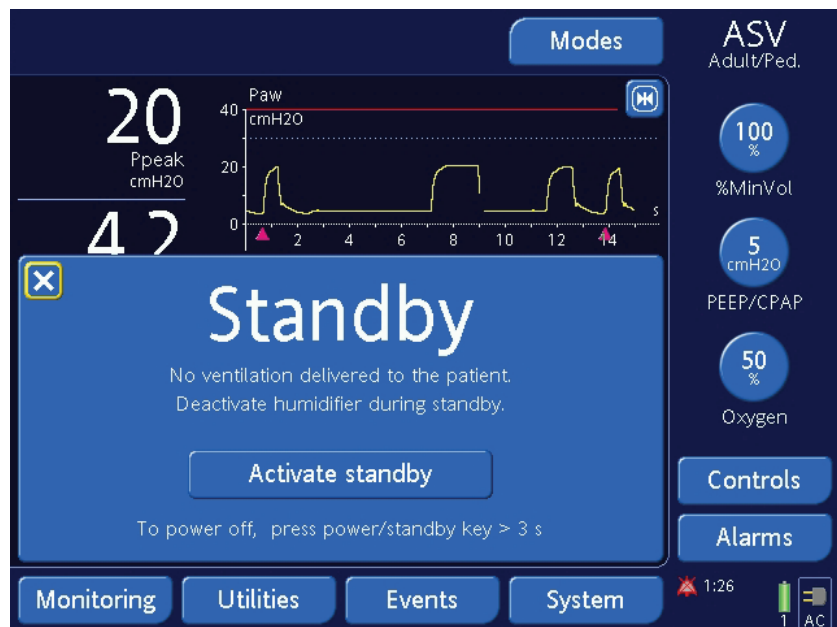


Figure 9-2. Activate Standby window

The **Standby** window (Figure 9-3) opens. During standby, the window shows the elapsed time since standby was started.

To end standby, either select Start ventilation, or press and quickly release the power switch. Ventilation resumes with the previous settings.

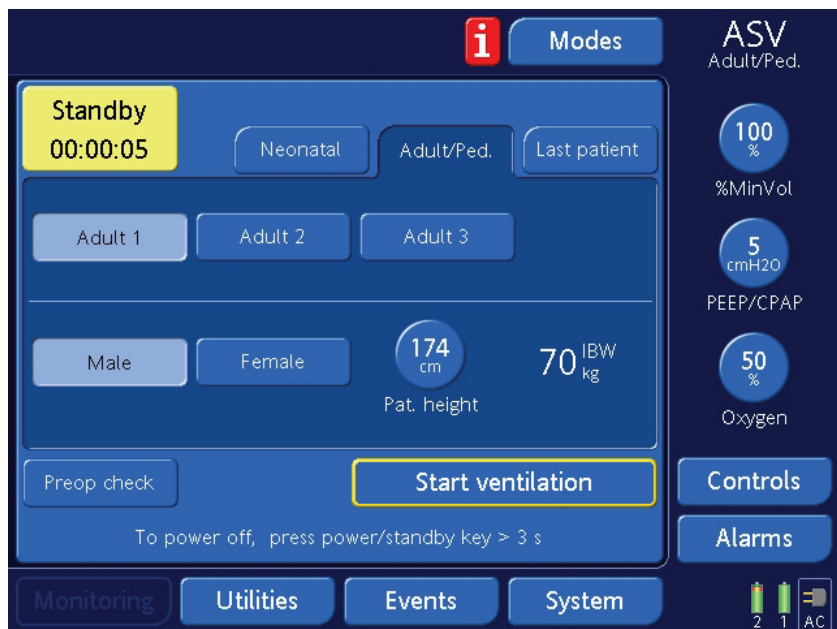


Figure 9-3. Standby window

9.2 O₂ enrichment

NOTE:

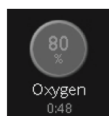
- Oxygen alarms are suppressed while the O₂ enrichment function is active.
- O₂ enrichment is not available with low pressure oxygen mode

In the adult patient group the O₂ enrichment function delivers 100% oxygen for 2 minutes. In the neonatal patient group the applied oxygen concentration during the enrichment maneuver is increased by 25% of the last oxygen setting (e.g. last oxygen setting 40%, resulting oxygen concentration during O₂ enrichment maneuver 50%). This is useful for pre- or post-oxygenation before/after tracheal suctioning or for other clinical applications.

To start oxygen enrichment, press the O₂ enrichment key. After a short time, which is required for the oxygen concentration to rise, the HAMILTON-C2 starts delivering 100% oxygen (adult and pediatric) or the current oxygen setting increased by 25% of the setting (infant/neonate). Afterwards the HAMILTON-C2 resets the concentration to the previous operator-set value.

The currently applied oxygen concentration is displayed on the oxygen control knob (green).

To terminate delivery of O₂ enrichment before the 2-min period is up, press the key again or activate manually the oxygen control knob. The oxygen control knob displays the last value set, which can now be adjusted. The HAMILTON-C2 resumes ventilation at the set oxygen concentration.



During O₂ enrichment the oxygen knob displays the currently applied oxygen connection (value displayed in green.)

9.3 Suctioning tool

NOTE:

- You CANNOT use the suctioning tool during NIV, NIV-ST and nCPAP-PS.
 - The pre- and post oxygenation is displayed with green O₂ control and timer (maximum 120 seconds)
 - The suctioning tool is not available with low pressure oxygen supply.
-

During suctioning, the patient's secretion can escape from the tubing. By using the suctioning tool the ventilation stops and prevents that secretion escapes.

The suctioning tool is directly accessible using the O₂ enrichment key.

1. To perform the suctioning maneuver press the O₂ enrichment key for pre-oxygenation.
2. Disconnection terminates the ventilation and begins the maneuver. For 60 seconds, all alarms are completely suppressed.

-
3. After reconnection the post-oxygenation starts and again for 60 seconds all acoustic alarms are suppressed. The alarm message and lamp is still active.
 4. To terminate the pre- and post oxygenation maneuver press the O2 enrichment key.

9.4 Manual breath/inspiratory hold

This function lets you deliver a manually triggered breath or perform an inspiratory hold maneuver.

To deliver a manual breath only, press and release the key during exhalation. Do not press the key quickly and repeatedly. The manual breath uses the mandatory breath settings (standard or operator-set).

If you try to initiate a manual breath during the early stage of inspiration or the early stage of exhalation, the breath will not be delivered.

To perform an inspiratory hold, hold the key down during any breath phase. If the ventilator is in exhalation, it delivers a mandatory breath, then performs a hold maneuver until the key is released, up to 15 s additional to the set inspiratory time. If the ventilator is in inspiration, it performs a hold maneuver at the end of inspiration, lasting until the key is released, for up to 15 s additional.

9.5 Nebulizer

CAUTION

- **Do not use an expiratory filter or HME in the patient's breathing circuit during nebulization. Nebulization can cause an expiratory side filter to clog, substantially increasing flow resistance and impairing ventilation.**
 - **To prevent the expiratory valve from sticking due to nebulized medications, use only medications approved for nebulization and regularly check and clean the expiratory valve.**
-

NOTE:

- The pneumatic nebulizer is inactive when low-flow oxygen is used.
 - Delivered ventilation is compensated for the contribution of the internal nebulizer so that the expected volume and pressure are delivered.
 - The nebulization is inactive for ventilation of neonates.
-

The HAMILTON-C2's pneumatic nebulization function powers a standard inline nebulizer for delivery of prescribed medications in the ventilator circuit. When nebulization is active, the nebulizer flow is synchronized with the inspiratory phase of each breath for 30 min. Nebulization can be activated in all modes of ventilation.

To start nebulization, press the nebulizer on/off key. To terminate nebulization before the set time, press the key again.

For effective nebulization, use a pneumatic nebulizer jar as specified in Table 1-1. Section 2.6 describes how to install the nebulizer.

9.6 Print screen

The print screen function saves a JPG file of the current ventilator screen to a USB memory key. To create a screen shot, insert an USB memory key; then press the Print screen key while the desired screen is shown.

The filename takes this format:

screenshot_yyyymmdd_hhmmss.jpg

where:

yyyy is the year

mm is the month

dd is the date

hh is the hour (in 24-hour format)

mm is the minute

ss is the second

10 Maintenance

10.1	Introduction	10-2
10.2	Cleaning, disinfection and sterilization	10-2
	10.2.1 General guidelines for cleaning	10-7
	10.2.2 General guidelines for chemical disinfection	10-7
	10.2.3 General guidelines for autoclave, ETO or plasma sterilization	10-8
10.3	Preventive maintenance	10-9
	10.3.1 Servicing the air intake and fan filters	10-10
	10.3.2 Replacing the batteries	10-13
	10.3.3 Charging and calibrating the batteries	10-14
	10.3.4 Replacing the oxygen cell	10-14
10.4	Storage	10-15
10.5	Repacking and shipping	10-15

10.1 Introduction

Follow these maintenance procedures to ensure the safety and reliability of the HAMILTON-C2. All the procedures in this manual are intended to be performed by the operator. For further maintenance, contact your service representative.

10.2 Cleaning, disinfection and sterilization

CAUTION

- To minimize the risk of bacterial contamination or physical damage, handle bacteria filters with care.
 - To prevent patient exposure to sterilizing agents and to prevent premature deterioration of parts, sterilize parts using the techniques recommended in this section only.
 - To reduce the risk of electrical shock, disconnect electrical power from the ventilator before cleaning.
-

NOTE:

- Do not reuse single-use breathing circuit parts and other accessories, including Flow Sensors. They must be discarded after single use.
- Do not attempt to sterilize the interior of the ventilator.
- Do not attempt to sterilize the whole ventilator with ETO gas.
- Exposure to sterilizing agents may reduce the useful life of certain parts. Using more than one sterilization technique on a single part may damage a part.
- Because sanitation practices vary among institutions, HAMILTON MEDICAL cannot specify specific practices that will meet all needs or be responsible for the effectiveness of these practices. This manual provides general guidelines only and with validated cleaning, disinfection, and sterilization methods only. It is the user's responsibility to ensure the validity and effectiveness of the actual methods used.

The following subsections provide general guidelines for cleaning and decontaminating parts. Table 10-1 tells you the specific methods that are applicable to each HAMILTON-C2 part. For parts not supplied by HAMILTON MEDICAL, follow the manufacturers' guidelines. Do not attempt cleaning procedures unless specified by HAMILTON MEDICAL or the original manufacturer.

After cleaning and decontaminating parts, perform any required tests and calibrations described in Section 3.

**Table 10-1. Decontamination methods for
HAMILTON-C2 parts**

Part (material)	How to decontaminate	Remarks
Ventilator exterior, including housing, gas supply hoses, and power cord	Wipe with an appropriate bactericidal agent after each patient use	Do not use alcohol and chloric substances as a disinfectant. It does not harm the ventilator but it has not been proven to be an effective bactericidal or bacteriostatic. Do not clean the ventilator interior. This can damage internal parts.
Touchscreen	Dampen a soft cloth with isopropyl alcohol or a nonabrasive glass cleaner and wipe the screen.	Avoid using cleaners other than glass cleaners. Do not use any vinegar-based solutions. Avoid using gritty cloths. Handle the touchscreen with care. To facilitate cleaning the touchscreen during ventilation, use the screen lock key.
Flow Sensor, reusable	Chemically disinfect or gas (ETO or plasma) sterilize	Mild alkaline agents can be used for cleaning. Hard brushes or other materials may damage the flap or connector and must not be used. Use disinfectants recommended for plastic materials. Disinfectants including ASP CIDEX®, Schülke & Mayr Gigasept® FF, or Henkel-Ecolab Incidur® have been tested according to the manufacturers' guidelines. After cleaning, visually inspect the Flow Sensor body, tubings, and internal flap. Discard the Flow Sensor if there is any sign of damage or if it cannot be calibrated. Do not steam sterilize.

Table 10-1. Decontamination methods for HAMILTON-C2 parts (continued)

Part (material)	How to decontaminate	Remarks
CO2 sensor	Clean and disinfect the outside by wiping with a cloth dampened with 70% isopropyl alcohol, a 10% aqueous solution of sodium hypochlorite (bleach), disinfectant spray cleaner such as Steris Coverage® Spray HB, ammonia, or mild soap. Wipe down with a clean water-dampened cloth to rinse, and dry before use. Make sure the sensor windows are clean and dry before reuse.	Always disconnect the CO2 sensor before cleaning. Do not immerse or attempt to sterilize the sensor. Before reusing the sensor, make sure the windows are dry and residue-free, and that the sensor has not been damaged during handling or by the cleaning process. Replace if damaged or if excessive secretions are observed.
	WARNING Reusing, disassembling, cleaning, disinfecting, or sterilizing the single-use CO2 airway adapter may compromise its functionality and system performance, leading to a possible user or patient hazard. Performance is not guaranteed if an item labeled as single-use is reused.	

Table 10-1. Decontamination methods for HAMILTON-C2 parts (continued)

Part (material)	How to decontaminate	Remarks
CO2 sensor airway adapter, reusable (polyetherimide, aluminum, black oxide finish, Al2O3-sapphire)	Steam autoclave (adult adapters only) at 121 °C (250 °F) for 20 min, unwrapped; pasteurize; chemically disinfect; or ETO sterilize.	Acceptable chemical disinfectants include 70% isopropyl alcohol, a 10% aqueous solution of sodium hypochlorite (bleach), a 2% glutaraldehyde solution such as CIDEX, Steris System 1®, or ammonia (refer to the disinfectant manufacturer's instructions for use). Rinse with sterile water and dry. With proper care and if not otherwise damaged, adapters can be disinfected/sterilized according to the stated validated methods at least 100 times. Before reusing the adapter, make sure the windows are dry and residue-free, and that the adapter has not been damaged during handling or by the cleaning/sterilizing process. Replace if damaged or if excessive secretions are observed.
Expiratory valve membrane (silicone rubber)	Steam autoclave	Inspect the membrane for damage; replace if necessary. Replace after 40 autoclave cycles at 134° C or 273° F. ¹
Expiratory valve housing (PA12 polyamide plastic)	Steam autoclave	Inspect the membrane for damage; replace if necessary. Replace after 40 autoclave cycles at 134° C or 273° F.
Other breathing circuit parts or accessories	Follow the manufacturer's guidelines	

1. Tested at 137 °C for 18 min.

10.2.1 General guidelines for cleaning

NOTE:

- To prevent damage to breathing circuit parts, do not clean with hard brushes, pointed instruments, or rough materials.
 - To prevent damage to breathing circuit parts, follow the soap manufacturer's guidelines. Exposure to soap solution that is stronger than recommended can shorten the useful life of some products. Soap residue can cause blemishes or fine cracks, especially on parts exposed to elevated temperatures during sterilization.
-

Clean the HAMILTON-C2 parts as follows:

1. Disassemble parts. Breathing circuits must be disassembled completely.
2. Wash parts in warm water and soap or mild detergent solution.
3. Rinse parts thoroughly with clean, warm water.
4. Air dry.
5. Inspect all parts, and replace if damaged.
6. If you will sterilize or disinfect the part, continue with the appropriate sterilization/disinfection procedure. If you will not sterilize or disinfect the part, reassemble and reinstall parts, and perform any required tests.

10.2.2 General guidelines for chemical disinfection

NOTE:

Table 10-1 lists materials of construction for the HAMILTON-C2 parts. To prevent premature deterioration of parts, make sure the disinfecting chemical is compatible with the part material.

Disinfect the HAMILTON-C2 parts as follows:

1. Disassemble.
2. Clean.
3. Disinfect with a mild bactericidal chemical solution compatible with the part's materials of construction. Specific disinfectants given in have been tested according to the manufacturers' guidelines. Other brand names with similar active ingredients may also be suitable.
4. Reassemble and reinstall parts, and perform any required tests.

10.2.3 General guidelines for autoclave, ETO or plasma sterilization

NOTE:

Sterilize using a validated sterilization procedure (e.g. autoclave at 134 °C or 273 °F for 10 min, ETO sterilize at 55 °C or 131 °F or plasma sterilize at 37 to 50 °C or 99 to 122 °F).

Autoclave, ETO or plasma sterilize the HAMILTON-C2 parts as follows:

1. Clean.
2. Reassemble.
3. Inspect.
4. Perform any required tests.

10.3 Preventive maintenance

NOTE:

- HAMILTON MEDICAL recommends that you document all maintenance procedures.
 - Dispose of all parts removed from the device according to your institution's protocol. Follow all local, state, and federal regulations with respect to environmental protection, especially when disposing of the electronic device or parts of it (for example, oxygen cell, batteries).
-

Perform preventive maintenance on your HAMILTON-C2 according to the schedule in Table 10-2.

The following subsections provide details for some of these preventive maintenance procedures.

Table 10-2. Preventive maintenance schedule

Interval	Part/accessory	Procedure
Between patients and according to hospital policy	Breathing circuit (including mask, inspiratory filter, Flow Sensor, nebulizer jar, expiratory valve cover and membrane)	Replace with sterilized or new single-use parts. Run the tightness test and the Flow Sensor calibration (Section 3.3.2).
	Entire ventilator	Run the preoperational check (Section 3.2).
Every 2 days or according to hospital policy	Breathing circuit	Empty any water from breathing tubes or water traps. Inspect parts for damage. Replace as necessary.
Every month (or more often, if required)	Air intake dust filters and fan filter	Check for dust and lint. If needed, clean or replace.

Table 10-2. Preventive maintenance schedule (continued)

Interval	Part/accessory	Procedure
Every 6 months (while ventilator is in storage)	Batteries	Recharge batteries by plugging ventilator into ac power source for at least 4 h.
Yearly or every 5000 h, whichever comes first, or as necessary	Oxygen cell	Replace if depleted.
	NOTE: Oxygen cell life specifications are approximate. The actual cell life depends on operating environment. Operation at higher temperatures or higher oxygen concentrations shortens cell life.	
	Air intake HEPA filter	Replace.
	Ventilator	Perform service-related preventive maintenance. ¹
	LCD backlight	Replace. ¹
Every 20,000 h	Turbine	Replace. ¹
Every 5 years (30,000 h)	Ventilator	Perform service-related preventive maintenance. ¹

1. Must be done by a HAMILTON MEDICAL authorized service engineer according to instructions in the HAMILTON-C2 service manual.

10.3.1 Servicing the air intake and fan filters

Service the air intake and fan filters as follows (Figure 10-1):

1. Remove the filter cover (1).
2. Remove the two air intake dust filters (2). Pull up the retaining clip and pull out the HEPA filter. Install a new HEPA filter as required. Install new dust filters or wash the existing filters in a mild soap solution, rinse, dry, and reinstall.

3. Remove the fan filter (**3**). Install a new fan filter or wash the existing filter in a mild soap solution, rinse, dry and reinstall.
4. Reinstall the filter cover.



Figure 10-1. Removing the filter cover

- 1** Air intake dust filters
- 2** Fan filter
- 3** Filter cover



Figure 10-2. Removing the air intake filters

- 1** Air intake HEPA filter retaining clip
- 2** Air intake HEPA filter
- 3** Cooling Fan air intake filter
- 4** Air intake dust filter

10.3.2 Replacing the batteries

NOTE:

- To ensure that the ventilator always has battery backup, keep locked battery 1 in the ventilator at all times during ventilator operation. Battery 2 may be hot swapped while the ventilator is operating.
 - Because of damage of the battery door lock the batteries in the correct position.
-

Open the battery door (1). To remove battery 1 (2), turn the retaining screw until the battery is released. To remove battery 2 (3), press on the tab, and slide the battery out of its housing. Replace with a newly charged battery (Figure 10-3).

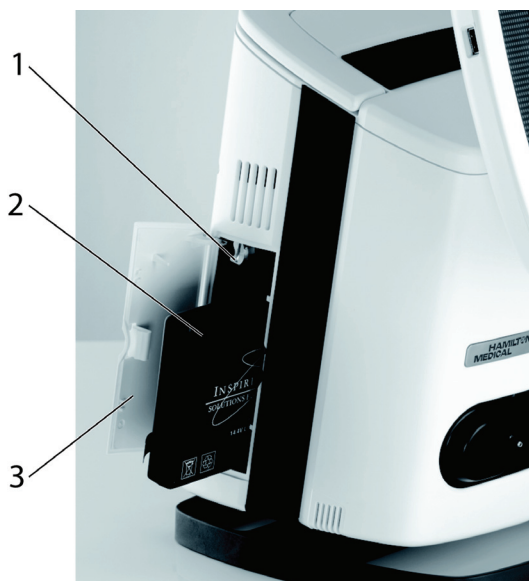


Figure 10-3. Removing battery 2

- 1 Battery 1
- 2 Battery 2
- 3 Door

10.3.3 Charging and calibrating the batteries

CAUTION

**The charger/calibrator item is not a Medical device.
It has to be used outside of the patient room.**

You can charge and calibrate the HAMILTON-C2's "smart" batteries with a HAMILTON MEDICAL supplied charger/calibrator (PN 369104). Calibrating the batteries allows the ventilator to accurately read the remaining battery charge.

Charge and calibrate the batteries following the instructions supplied with the charger/calibrator.

10.3.4 Replacing the oxygen cell

CAUTION

To reduce the risk of explosion, do not burn the oxygen cell or force the cell open.

NOTE:

- Replace the oxygen cell with genuine HAMILTON MEDICAL parts only; otherwise, oxygen measurement will not function.
 - To prevent leakage within the ventilator, make sure an oxygen cell is installed at all times, even if you use an external monitor or disable oxygen monitoring.
 - To prevent a permanent alarm use special HAMILTON MEDICAL oxygen cells only.
-

To remove the oxygen cell, pull off its cover, then disconnect and remove the cell (Figure 10-4). Install the new cell; then apply the oxygen cell cover. Run the oxygen cell calibration (see Section 3).



Figure 10-4. Replacing the oxygen cell

- 1 Oxygen cell
- 2 Cover

10.4 Storage

To maintain the battery charge and to prolong the life of the batteries, keep the ventilator connected to its primary power source. Have the batteries recharged every 6 months, depending on storage conditions (see specifications in Appendix A).

10.5 Repacking and shipping

If you must ship the ventilator, use the original packing materials. If these materials are not available, contact your HAMILTON MEDICAL representative for replacement materials.

A Specifications

A.1	Physical characteristics	A-2
A.2	Environmental requirements	A-3
A.3	Pneumatic specifications	A-3
A.4	Electrical specifications	A-4
A.5	Control settings	A-5
A.6	Monitored parameters	A-13
A.7	Alarms	A-27
A.8	Configuration specifications	A-31
A.9	Ventilator breathing system specifications	A-33
A.10	Other technical data	A-34
A.11	Standards and approvals	A-36
A.12	EMC declarations (IEC 60601-1-2)	A-37
A.13	Warranty	A-42
A.14	Miscellaneous	A-43

A.1 Physical characteristics

Table A-1. Physical characteristics

Weight	9.5 kg (21 lb) 38.5 kg (85 lb) with standard trolley
Dimensions	See Figure A-1

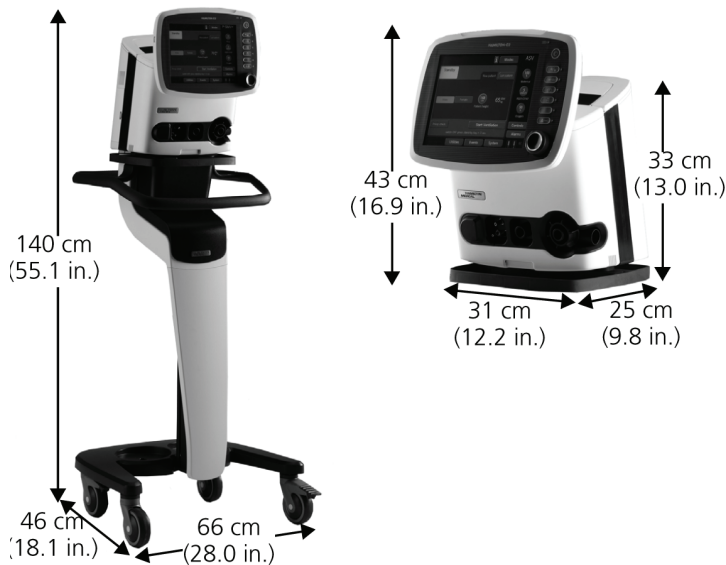


Figure A-1. HAMILTON-C2 dimensions

A.2 Environmental requirements

Table A-2. Environmental requirements

Temperature	Operating: 5 to 40 °C (41 to 104 °F) Storage: -20 to 60 °C (-4 to 140 °F)
Relative humidity	Operating/storage: 10 to 95%, non-condensing
Altitude	Up to 4000 m (13,120 ft) above sea level

A.3 Pneumatic specifications

Table A-3. Pneumatic specifications

High-pressure oxygen inlet	Pressure: 2.8 to 6 bar / 280 to 600 kPa / 41 to 87 psi Flow: 40 to 120 l/min STPD Connector: DISS (CGA 1240) or NIST
Low-pressure oxygen inlet	Peak pressure: ≤ 6 bar/600 kPa/87 psi Flow: ≤ 15 l/min Connector: Quick-coupling system, compatible with Colder Products Company® (CPC) PMC Series
Air supply	Integrated turbine
Gas mixing system	Delivered flow: 240 l/min peak flow, 120 l/min continuous flow, 4 to 20 l/min continuous base flow Delivered pressure: 0 to 60 cmH ₂ O
Inspiratory outlet (To patient port)	Connector: ISO 15 mm female/22 mm male conical
Expiratory outlet (From patient port)	Connector (on expiratory valve): ISO 15 mm female/ 22 mm male conical

A.4 Electrical specifications

Table A-4. Electrical specifications

Input power	100 to 240 V AC $\pm 10\%$, 50/60 Hz or 12 to 24 V DC $\pm 10\%$
Power consumption	50 W typical, 150 W maximum
Batteries	NOTE: Battery life indications are approximate. The actual battery life depends on ventilator settings, battery age, and level of battery charge. To ensure maximum battery life, maintain a full charge and minimize the number of complete discharges. Electrical specifications for battery 1 or 2: 14.4 V DC, 6.6 Ah, 3.5 A Type: Lithium-ion, supplied by HAMILTON MEDICAL only Operating time with one battery in use (with turbine in use and with these settings: C = 15 ml/cmH₂O, Rate = 10 b/min, P_{insp} = 10 cmH₂O, PEEP/CPAP = 5 cmH₂O): 2.5 h minimum, 3.0 h typical. This operating time applies to a new, fully charged battery not exposed to extreme temperatures. The actual operating time depends on battery age and on how the battery is used and recharged. Recharge time for battery 1 and/or 2: 4 h minimum while ventilator is connected to either DC between 20 and 27 V or DC. Storage: -20 to 60 °C, $\leq$ 95% relative humidity. Storage place should be free from vibration, dust, direct sunlight, moisture, and corrosive gases, and with a recommended temperature range < 21 °C. Extended exposure to temperatures above 45 °C could degrade battery performance and life.

A.5 Control settings

Table A-5 and Table A-6 are alphabetical lists of the HAMILTON-C2's control settings, ranges, and resolutions. Table A-6 lists the control settings that apply to the various ventilation modes.

Table A-5. Control setting ranges and resolutions (adult)

Setting	Range	Resolution	Default settings
Apnea (backup)	On, Off	--	On
ETS (expiratory trigger sensitivity)	5 to 80 % (of inspiratory peak flow)	5 %	25 % ¹
Flowtrigger	Off, 1 to 20 l/min (S)CMV+ and PCV+ modes 1 to 20 l/min (other modes)	1 l/min	5 l/min ¹
Gender	Male, Female	--	Male ¹
I:E	1:9 to 4:1 (1:599 to 149:1 in Duo-PAP)	--	1:2
Loudness (alarm)	1 to 10	1	5
%MinVol (% minute volume)	25 to 350 %	5%	100 % ¹

Table A-5. Control setting ranges and resolutions (adult)

Setting	Range	Resolution	Default settings
Mode	(S)CMV+, PCV+, SIMV+, PSIMV+, SPONT, ASV, NIV, NIV-ST, DuoPAP, APRV	--	ASV ¹
Oxygen	21 to 100 %	1 %	50 % ¹
Pasvlimit	5 to 60 cmH ₂ O	1 cmH ₂ O	30 cmH ₂ O ¹
Pat. height (patient height)	30 to 250 cm (3 to 139 kg IBW)	2 cm	174 cm ¹
Pcontrol (con- trol pressure, added to PEEP/ CPAP)	5 to 60 cmH ₂ O	1 cmH ₂ O	15 cmH ₂ O
PEEP/CPAP	0 to 35 cmH ₂ O	1 cmH ₂ O	5 cmH ₂ O ¹
Pinsp (inspira- tory pressure, added to PEEP/ CPAP)	5 to 60 cmH ₂ O	1 cmH ₂ O	Table C-6
P-ramp	0 to 2000 ms	25 ms	50 ms ¹
Psupport (pres- sure support, added to PEEP/ CPAP)	0 to 60 cmH ₂ O	1 cmH ₂ O	15 cmH ₂ O
Phigh (Duo- PAP)	0 to 60 cmH ₂ O	1 cmH ₂ O	20 cmH ₂ O ¹
Phigh (APRV)	0 to 60 cmH ₂ O	1 cmH ₂ O	Table C-6
Plow (APRV)	0 to 35 cmH ₂ O	1 cmH ₂ O	5 cmH ₂ O ¹

Table A-5. Control setting ranges and resolutions (adult)

Setting	Range	Resolution	Default settings
Rate	4 to 80 b/min: (S)CMV+, PCV+ 5 to 80 b/min: PSIMV+, NIV- ST 1 to 80 b/min: SIMV+, Duo- PAP	1 b/min	Table C-6
Sigh	On, Off	--	Off
Thigh (Duo- PAP/APRV)	0.1 to 40 s	0.1 s	2 s for DuoPAP, for APRV see Table B-2
Tl (inspiratory time)	0.1 to 12 s	0.1 s	Based on rate and I:E = 1:2
Tl max (maxi- mum inspira- tory time, spontaneous breaths) (NIV and NIV-ST)	1.0 to 3.0 s	0.05 s	1.5 s
Tlow (APRV)	0.2 to 40 s	0.01 s (< 1 s) 0.05 (≥ 15 and < 3s) 0.1 (≥ 3 s)	see Table B-2
TRC Expiration	ON, OFF	-	ON
TRC Tube type	ET tube, Trach tube	-	
TRC Compens- ation	0 to 100 %	10 %	80 %

Table A-5. Control setting ranges and resolutions (adult)

Setting	Range	Resolution	Default settings
TRC Compensation	0 to 100 %	10 %	80 %
VT/kg Tidal volume per weight	6 to 12 ml/kg	1 ml/kg	7 ml/kg

1. Configurable in the operating range.

Table A-6. Control setting ranges and resolutions (neonatal)

Setting	Range	Resolution	Default settings
Apnea (backup)	On, Off	--	On
ETS (expiratory trigger sensitivity)	5 to 80 % (of inspiratory peak flow)	5 %	15 % ¹
Flowtrigger	Off, 0.1 to 20 l/min (S)CMV+, PCV+ modes and nCPAP-PS 0.1 to 20l/min (other modes)	0.1 l/min < 2 l/min 0.5 l/min > 2l/min ¹	3
I:E	1:9 to 4:1	--	1:2
Ideal body weight	0.2 to 30 kg	0.1 < 15 0.5 (≥15 AND < 30)	0.5 kg
Loudness (alarm)	1 to 10	1	5

Table A-6. Control setting ranges and resolutions (neonatal)

Setting	Range	Resolution	Default settings
Mode	(S)CMV+, PCV+, SIMV+, PSIMV+, SPONT, nCPAP-PS, NIV, NIV-ST, DuoPAP, APRV	--	
Oxygen	21 to 100 %	1 %	50 % ¹
Pcontrol (control pressure, added to PEEP/CPAP) [Neo]	3 to 60 cmH ₂ O	0.5 cmH ₂ O	15 cmH ₂ O
PEEP/CPAP	0 to 25 cmH ₂ O	0.1 cmH ₂ O	5 cmH ₂ O ¹
Pinsp (inspiratory pressure, added to PEEP/CPAP)	3 to 60 cmH ₂ O	0.5 cmH ₂ O	15 cmH ₂ O
Pinsp in nCPAP-PS	0 to 60 cmH ₂ O	0.5 cmH ₂ O	15 cmH ₂ O
P-ramp	0 to 2000 ms	25 ms	50 ms ¹
Psupport (pressure support, added to PEEP/CPAP)	0 to 60 cmH ₂ O	0.5 cmH ₂ O	15 cmH ₂ O
Phigh (DuoPAP, APRV)	0 to 60 cmH ₂ O	0.5 cmH ₂ O	20 cmH ₂ O ¹
Plow (APRV)	0 to 25 cmH ₂ O	0.1 cmH ₂ O	5 cmH ₂ O ¹

Table A-6. Control setting ranges and resolutions (neonatal)

Setting	Range	Resolution	Default settings
Rate	15 to 150 b/min: (S)CMV+, PCV+, PSIMV+, NIV-ST and nCPAP-PS	1 b/min	50 b/min for 0.2 to 1.2 kg IBW 40 b/min for 1.3 to 2.9 kg IBW Table C-6 applies for IBW > 3
Thigh (DuoPAP/APRV)	0.1 to 40 s	0.01 (<1 s) 0.05 (≥ 1 s AND <3 s) 0.1 ≥ 3 s	0.4 s for DuoPAP, for APRV see Table B-2
TI (inspiratory time)	0.1 to 12 s	0.1 s	Based on Rate and I:E = 1:2
TI max (maximum inspiratory time, spontaneous breaths) (NIV and NIV-ST)	0.25 to 3.0 s	0.05 s (≥ 1 s)	1.0 s
Tlow (APRV)	0.2 to 40 s	0.01 s (< 1 s) 0.05 (≥ 15 and < 3s) 0.1 (≥ 3 s)	Table B-2
TRC Expiration	ON, OFF	-	ON
TRC Tube type	ET tube, Trach tube or TRC OFF	-	TRC OFF
TRC Tube size	2.5 to 5.0 mm	0.5 mm	3.5 mm
TRC Compensation	0 to 100 %	10 %	80 %

Table A-6. Control setting ranges and resolutions (neonatal)

Setting	Range	Resolution	Default settings
Vt (tidal volume)	2 to 300 ml	0.1 ml (< 10 ml) 1 ml (≥ 10 ml) 10 ml (≥ 100 ml)	IBW*VT/kg
VT/kg Tidal volume per weight	6 to 12 ml/kg	1 ml/kg	7 ml/kg

1. Configurable in the operating range.

Table A-7. Controls active in HAMILTON-C2 ventilation modes

	Closed-loop mode	Mandatory modes		SIMV modes				DuoPAP/APRV		Pressure support modes	
Mode	ASV	PCV+	(S)CMV+	PSIMV+	SIMV+	NIV-ST	nCPAP-PS	DuoPAP	APRV	SPONT	NIV
Timing	--	Rate									
	--	I:E		TI		Thigh					
Mandatory breaths	--	Pcontrol	Vt	Pinsp	Vt	Pinsp	Pinsp	Phigh			
Spontaneous breaths	--			Psupport				--		Psupport	
	ETS	--		ETS				--		ETS	
	--					Tlmax		--		Tlmax	
Baseline pressure	PEEP/CPAP		Flow								
General	Flowtrigger										
	P-ramp										
	Oxygen										
	Gender				--	Gender					
	Patient height				--	Patient height					
ASV-specific	%MinVol										
	Pasvlimit										

A.6 Monitored parameters

Table A-8 and Table A-9 are alphabetical lists of monitored parameter ranges, resolutions, and accuracies, including those of the Vent Status panel. Table A-10 and Table A-11 list the ranges of the real-time curves and loops. Pressure, flow, and volume measurements are based on readings from the Flow Sensor, and they are expressed in BTPS (body temperature and pressure saturated). You can choose to show all monitored parameters as 1-, 6-, 12-, or 24-hour trends.

Table A-8. Monitored parameter ranges, resolutions and accuracies (adult)

Parameter	Range	Resolution	Accuracy
Pressure			
(Ppeak, Pmean, PEEP/CPAP)	0 to 80 cmH2O	0.1 cmH2O for < 10 cmH2O 1 cmH2O for ≥ 10 cmH2O	± (2 % of full scale reading + 4 % of actual reading)
AutoPEEP	0 to 80 cmH2O	0.1 cmH2O for < 10 cmH2O 1 cmH2O for ≥10 cmH2O	--
Pplateau	0 to 80cmH2O	0.1 cmH2O for < 10 cmH2O 1 cmH2O for ≥ 10 cmH2O	± (2 % of full scale reading + 4 % of actual reading)
Flow			
Insp Flow	0 to 210 l/min	0.1 l/min for < 100 l/min 1 l/min for ≥ 100 l/min	±10 % of actual reading or ±20 ml/s, whichever is greater

Table A-8. Monitored parameter ranges, resolutions and accuracies (adult)

Parameter	Range	Resolution	Accuracy
Exp Flow	0 to 210 l/min	0.1 l/min for < 100 l/min 1 l/min for $\geq$ 100 l/min	± 10 % of actual reading or ± 20 ml/s, whichever is greater
Volume			
VTE, VTI	0 to 9000 ml	0.1 l/min for < 10 l/min 1 l/min for $\geq$ 10 l/min	± 10 % of actual reading or ± 10 ml, whichever is greater
VTE NIV	0 to 9000 ml	0.1 l/min for < 10 l/min 1 l/min for $\geq$ 10 l/min	± 10 % of actual reading or ± 10 ml, whichever is greater
ExpMinVol, MVSpont, MinVol NIV, MVSpont NIV	0.0 to 99.9 l/min	0.01 l/min for < 3.0 l/min 0.1 l/min for $\geq$ 3.0 l/min	± 10 % of actual reading or ± 0.3 l/min, whichever is greater
Leak	0 to 100 %	1 %	± 10 % of actual reading (for leak volumes between 100 and 200 ml)
Time			
I:E	9.9:1 to 1:99	1 for 1:10 to 1:99 0.1 for 9.9:1 to 1:9.9	--

Table A-8. Monitored parameter ranges, resolutions and accuracies (adult)

Parameter	Range	Resolution	Accuracy
fTotal, fSpont	0 to 999 b/min	1 b/min	±1 b/min
TI, TE	0.00 to 60.0 s	0.01 s for < 10.0 s 0.1 s for ≥ 10.0 s	±0.1 s
Other calculated and displayed parameters			
Cstat	0 to 200 ml/cmH ₂ O	0.1 ml/cmH ₂ O for < 100 ml/cmH ₂ O 1 ml/cmH ₂ O for ≥ 100 ml/cmH ₂ O	--
P0.1	-99 to 0 cmH ₂ O	0.1 (> -10) 1 (≤ -10)	--
PTP	0 to 100 cmH ₂ O*s	0.1	--
RCexp	0.0 to 99.9 s	0.01 s for < 10.0 s 0.1 s for ≥ 10.0 s	--
Rinsp	0 to 999 cmH ₂ O/l/s	1 cmH ₂ O/l/s	--
IBW	3 to 139 kg	1 kg	--
VTESpont	0 to 9000 ml	0.1 (<10) 1 (≥ 10)	±10 % or ± 10ml, whichever is greater
Oxygen			

Table A-8. Monitored parameter ranges, resolutions and accuracies (adult)

Parameter	Range	Resolution	Accuracy
Oxygen	18 to 105 %	1 %	±(volume fraction of 2.5 % + 2.5 % of actual reading)
CO2			
FetCO2	0 to 20.0%	0.1%	CO2 (BTPS): 0 to 40 mmHg: ±2 mmHg 41 to 70 mmHg: ±5% of reading 71 to 100 mmHg: ±8% of reading 101 to 150 mmHg: ±10% of reading Above 80 BPM ±12% of reading for side-stream

Table A-8. Monitored parameter ranges, resolutions and accuracies (adult)

Parameter	Range	Resolution	Accuracy
PetCO ₂	0 to 150 mmHg	1 mmHg	CO ₂ (BTPS): 0 to 40 mmHg: ±2 mmHg 41 to 70 mmHg: ±5% of reading 71 to 100 mmHg: ±8% of reading 101 to 150 mmHg: ±10% of reading Above 80 BPM ±12% of reading for side-stream
slopeCO ₂ (for main-stream CO ₂ only)	0 to 9.99 %CO ₂ /l	0.01 %CO ₂ /l	
V _{talv} (for main-stream CO ₂ only)	0 to 9999 ml	1 ml	
V' _{alv} (for main-stream CO ₂ only)	0 to 20 l/min	0.01 l/min for < 1 l/min 0.1 l/min for ≥ 1 l/min	
V'CO ₂ (for main-stream CO ₂ only)	0 to 9999 ml/min	1 ml/min	

Table A-8. Monitored parameter ranges, resolutions and accuracies (adult)

Parameter	Range	Resolution	Accuracy
VDaw (for main-stream CO2 only)	0 to 999 ml	1 ml	
VDaw/VTE (for main-stream CO2 only)	0 to 100%	1%	
VeCO2 (for main-stream CO2 only)	0 to 999 ml	1 ml	
ViCO2 (for main-stream CO2 only)	0 to 999 ml	1 ml	
Vent Status panel			
Oxygen	21 to 40 %	1 %	--
PEEP	0 to 8 cmH ₂ O	1 cmH ₂ O	--
MinVol	0 to 350 % of normal minute ventilation expressed in l/min	5%	--
Pinsp	0 to 50 cmH ₂ O	1 cmH ₂ O	--
RSB	10 to 400 l/(l*min)	1 l/(l*min)	--

Table A-9. Monitored parameter ranges, resolutions and accuracies (neonatal)

Parameter	Range	Resolution	Accuracy
Pressure			
(Ppeak, Pmean, PEEP/CPAP)	0 to 80 cmH2O	0.1 cmH2O for < 10 cmH2O 1 cmH2O for ≥10 cmH2O	± (2 % of full scale reading + 4 % of actual reading)
AutoPEEP	0 to 80 cmH2O	0.1 cmH2O for < 10 cmH2O 1 cmH2O for ≥ 10 cmH2O	--
Pplateau	0 to 80cmH2O	0.1 cmH2O for < 10 cmH2O 1 cmH2O for ≥ 10 cmH2O	± (2 % of full scale reading + 4 % of actual reading)
Flow			
Insp Flow	0 to 30 l/min	0.1 l/min for < 100 l/min 1 l/min for ≥ 100 l/min	±10 % of actual reading or ±20 ml/s, whichever is greater
Exp Flow	0 to 30 l/min	0.1 l/min for < 100 l/min 1 l/min for ≥ 100 l/min	±10 % of actual reading or ±20 ml/s, whichever is greater
Volume			
ExpMinVol	0 to 99.9 l/min	0.01 l/min for < 3.0 l/min 0.1 l/min for ≥ 3.0 l/min	±10 % of actual reading or ± 0.3 l/min, whichever is greater

Table A-9. Monitored parameter ranges, resolutions and accuracies (neonatal)

Parameter	Range	Resolution	Accuracy
MinVolNIV	0 to 99.9 l/min	0.01 l/min for < 3.0 l/min 0.1 l/min for ≥ 3.0 l/min	±10 % of actual reading or ± 0.3 l/min, whichever is greater
VTE, VTI, VTE NIV	0 to 9000 ml	0.1 l/min for < 10 l/min 1 l/min for ≥ 10 l/min	±10 % of actual reading or ± 2 ml, whichever is greater
MVSpont, MVSpont NIV	0.0 to 99.9 l/min	0.01 l/min for < 3.0 l/min 0.1 l/min for ≥ 3.0 l/min	±10 % of actual reading or ± 0.3 l/min, whichever is greater
VTESpont	0 to 9000 ml	0.1 ml for < 10 ml 1 ml for ≥ 10 ml	±10 % of actual reading or ± 2 ml, whichever is greater
Leak	0 to 100 %	1 %	±10 % of actual reading (for leak volumes between 100 and 200 ml)

Table A-9. Monitored parameter ranges, resolutions and accuracies (neonatal)

Parameter	Range	Resolution	Accuracy
Time			
I:E	9.9:1 to 1:99	1 for 1:10 to 1:99 0.1 for 9.9:1 to 1:9.9	--
fSpont	0 to 999 b/min	1 b/min	±1 b/min
TE	0.00 to 60.0 s	0.01 s for < 10.0 s 0.1 s for ≥ 10.0 s	±0.1 s
Other calculated and displayed parameters			
Cstat	0 to 200 ml/cmH ₂ O	0.1 ml/cmH ₂ O for < 100 ml/cmH ₂ O 1 ml/cmH ₂ O for ≥ 100 ml/cmH ₂ O	--
P0.1	-99 to 0 cmH ₂ O	0.1 (> -10) 1 (≤ -10)	--
PTP	0 to 100 cmH ₂ O*s	0.1	--
RCexp	0.0 to 99.9 s	0.01 s for < 10.0 s 0.1 s for ≥ 10.0 s	--
Rinsp	0 to 999 cmH ₂ O/l/s	1 cmH ₂ O/l/s	--
Oxygen			

Table A-9. Monitored parameter ranges, resolutions and accuracies (neonatal)

Parameter	Range	Resolution	Accuracy
Oxygen	18 to 105%	1 %	±(volume frac- tion of 2.5 % + 2.5 % of actual reading)
CO2			
FetCO2	0 to 20.0%	0.1%	CO2 (BTPS): 0 to 40 mmHg: ±2 mmHg 41 to 70 mmHg: ±5% of reading 71 to 100 mmHg: ±8% of reading 101 to 150 mmHg: ±10% of reading Above 80 BPM ±12% of read- ing for side- stream

Table A-9. Monitored parameter ranges, resolutions and accuracies (neonatal)

Parameter	Range	Resolution	Accuracy
PetCO ₂	0 to 150 mmHg	1 mmHg	CO ₂ (BTPS): 0 to 40 mmHg: ±2 mmHg 41 to 70 mmHg: ±5% of reading 71 to 100 mmHg: ±8% of reading 101 to 150 mmHg: ±10% of reading Above 80 BPM ±12% of reading for side-stream
slopeCO ₂ (for main-stream CO ₂ only)	0 to 9.99 %CO ₂ /l	0.01 %CO ₂ /l	
V _{talv} (for main-stream CO ₂ only)	0 to 9999 ml	1 ml	
V' _{alv} (for main-stream CO ₂ only)	0 to 20 l/min	0.01 l/min for < 1 l/min 0.1 l/min for ≥ 1 l/min	
V'CO ₂ (for main-stream CO ₂ only)	0 to 9999 ml/min	1 ml/min	

Table A-9. Monitored parameter ranges, resolutions and accuracies (neonatal)

Parameter	Range	Resolution	Accuracy
VDaw (for main-stream CO2 only)	0 to 999 ml	1 ml	
VDaw/VTE (for main-stream CO2 only)	0 to 100%	1 %	
VeCO2 (for main-stream CO2 only)	0 to 999 ml	1 ml	
ViCO2 (for main-stream CO2 only)	0 to 999 ml	1 ml	

Table A-10. Real-time curves and loops (adult)

Parameter	Range
Real time curves	
Volume (V)	0 to 3200 ml
Flow	-300 to 300 l/min
Airway pressure (Paw)	-10 to 80 cmH2O
Time	0 to 30s
FCO2	0 to 10%
PCO2	0 to 100 mmHg
Loops	
Pressure/Volume	x: 0 to 3200 ml
	y: -10 to 80 cmH2O
Volume/Flow	x: 0 to 3200 ml
	y: -300 to 300 l/min
Pressure/Flow	x: -300 to 300 l/min
	y: -10 to 80 cmH2O
Volume/PCO2	x: 0 to 3200 ml
	y: 0 to 100 mmHg
Volume/FCO2	x: 0 to 32000 ml
	y: 0 to 10 %

Table A-11. Real-time curves and loops (neonatal)

Parameter	Range
Real time curves	
Volume (V)	0 to 300 ml
Flow	-30 to 30 l/min
Airway pressure (Paw)	-10 to 80 cmH2O
Time	0 to 30s
FCO2	0 to 10%
PCO2	0 to 100 mmHg
Loops	
Pressure/Volume	x: 0 to 300 ml
	y: -10 to 80 cmH2O
Volume/Flow	x: 0 to 300 ml
	y: -30 to 30 l/min
Pressure/Flow	x: -30 to 30 l/min
	y: -10 to 80 cmH2O

A.7 Alarms

Table A-12 and Table A-13 are alphabetical lists of the adjustable alarm ranges and resolutions. Table 8-2 describes other, nonadjustable alarms.

Table A-12. Adjustable alarm ranges and resolutions (adult)

Parameter	Operating range	Automatic settings	Resolution	Default settings
Apnea time	15 to 60 s	--	5 s	20 s ¹
ExpMinVol (low)	Off, 0.1 to 50 l/min (NIV, NIV-ST) 0.1 to 50 l/min (other modes)	0.6* ExpMinVol	0.1 l/min for < 1 l/min 0.5 l/min for ≥ 1 l/min and < 10 l/min 1 l/min for ≥ 10 l/min	0.6 * Rate * Vt
ExpMinVol (high)	0.1 to 50 l/min	1.5 * Rate * Vt	0.1 l/min for < 1 l/min 0.5 l/min for ≥ 1 l/min and < 10 l/min 1 l/min for ≥ 10 l/min	1.5 * Rate * Vt
fTotal (low)	0 to 99 b/min	fTotal*0.6	1 b/min	0 b/min
fTotal (high)	0 to 99 b/min	fTotal*1.4	1 b/min	40 b/min
Oxygen (low)	18 to 97%	- 5 % Vol. of setting	1%	45 %
Oxygen (high)	18 to 103%	+ 5 % Vol. of setting	1%	55 %

Table A-12. Adjustable alarm ranges and resolutions (adult)

Parameter	Operating range	Automatic settings	Resolution	Default settings
PetCO ₂ (low)	Off, 0 to 99 mmHg	- 25 % of the reading	1 mmHg	30 mmHg
PetCO ₂ (high)	Off, 1 to 100 mmHg	+ 25 % of the reading	1 mm Hg	60 mmHg
Pressure (high)	15 to 70 cmH ₂ O	Ppeak + 15 cmH ₂ O, minimum 40 cmH ₂ O	1 cmH ₂ O	40 cmH ₂ O
Pressure (low)	4 to 60 cmH ₂ O	PEEP	1 cmH ₂ O	PEEP
Vt (low)	Off, 10 to 3000 ml	0.5 * VTE	5 ml for < 500 ml 10 ml for 500 to 1000 ml 50 ml for > 1000 ml	0.5 * VTE
Vt (high)	Off, 10 to 3000 ml	1.5 * VTE	5 ml for < 500 ml 10 ml for 500 to 1000 ml 50 ml for > 1000 ml	1.5 * VTE

1. The default setting is configurable.

Table A-13. Adjustable alarm ranges and resolutions (neonatal)

Parameter	Operating range	Resolution	Default settings
Apnea time	5 to 60 s	1 s (<15) 5 s (≥ 15)	15 s ¹
ExpMinVol (low)	Off, 0.01 to 10 l/min	0.01 l/min for < 1 l/min 0.1 l/min for ≥ 1 l/min	0.6 * Rate * Vt
ExpMinVol (high)	0.03 to 10 l/min, OFF	0.01 l/min for < 1 l/min 0.1 l/min for ≥ 1 l/min	1.5 * Rate * Vt
fTotal (low)	0 to 200 b/min	1 b/min	0 b/min
fTotal (high)	2 to 210 b/min	1 b/min	45 b/min
Oxygen (low)	18 to 97%	1%	45 %
Oxygen (high)	18 to 103%	1%	55 %
PetCO ₂ (low)	Off, 0 to 99 mmHg	1 mmHg	30 mmHg
PetCO ₂ (high)	Off, 1 to 100 mmHg	1 mmHg	60 mmHg
Pressure (high)	15 to 70 cmH ₂ O	1 cmH ₂ O	40 cmH ₂ O
Pressure (low)	4 to 60 cmH ₂ O	1 cmH ₂ O	PEEP

Table A-13. Adjustable alarm ranges and resolutions (neonatal)

Parameter	Operating range	Resolution	Default settings
Vt (low)	Off, 0.1 to 300 ml	5 ml for < 500 ml 10 ml for 500 to 1000 ml 50 ml for > 1000 ml	0.5 * VTE
Vt (high)	Off, 0.1 to 300 ml	5 ml for < 500 ml 10 ml for 500 to 1000 ml 50 ml for > 1000 ml	1.5 * VTE

1. The default setting is configurable.

A.8 Configuration specifications

Table A-14 lists the configurable parameters, ranges, and resolutions.

Table A-14. Configuration specifications

Parameter	Range	Resolution	Default setting
General			
Language	English, Chinese, Czech, Danish, Dutch, French, German, Greek, Hungarian, Indonesian, Italian, Japanese, Korean, Norwegian, Polish, Portuguese, Russian, Serbian, Slovak, Spanish, Swedish, Turkish		English
Units	hPa, mbar, cmH ₂ O mmHg, Torr, kPa cm, inch	--	cmH ₂ O mmHg cm
More	HPO mode, LPO mode	--	HPO -mode
	Communications interface GALILEO identifier ON. HAMILTON-C2 identifier ON. Open VueLink	--	GALILEO identifier ON.

Table A-14. Configuration specifications

Parameter	Range	Resolution	Default setting
Graphics MMP	Pmean, PEEP/CPAP, Ppeak, ExpMinVol, VTI, VTE, VLeak, fTotal, fSpont, Oxygen, Cstat, Rinsp, I:E, TI, TE, MVSpont, AutoPEEP, P0.1, PTP, RCexp, Pplateau, VTESpont	--	Ppeak ¹ , ExpMinVol, VTE, fTotal
Settings	All mode, control, and alarm settings plus alarm loudness setting		Table A-5
Vt/IBW	6 to 12 ml/kg	1 ml/kg	10 ml/kg (adult) 7 ml/kg (neonatal)
Vent Status			
Oxygen	21 to 100 %	1 %	21 to 40 % ²
PEEP	0 to 35cmH ₂ O	1 cmH ₂ O	0 to 10cmH ₂ O ³
Pinsp	0 to 60cmH ₂ O	1 cmH ₂ O	0 to 8 cmH ₂ O
RSB	0 to 150 1/(l*min)	1 1/(l*min)	10 to 100 1/(l*min)
%fSpont	0 to 100 %	1 %	75 to 100 % ⁴

1. The default setting is configurable.

2. The low Oxygen setting is always 21%.

3. The low PEEP setting is always 0 cmH₂O.

4. The high %fSpont setting is always 100%.

A.9 Ventilator breathing system specifications

Table A-15 lists specifications for the HAMILTON-C2 ventilator breathing system.

Table A-15. Ventilator breathing system specifications

Parameter	Specification
Resistance ¹	Adult circuit (19 mm ID, flow of 60 l/min): Inspiratory limb: < 6 cmH ₂ O/60 l/min Expiratory limb: < 6 cmH ₂ O/60 l/min Pediatric circuit (15 mm ID, flow of 30 l/min): Inspiratory limb: < 6 cmH ₂ O/30 l/min Expiratory limb: < 6 cmH ₂ O/30 l/min Coaxial circuit (flow of 60l/min): Inspiratory limb: < 2.05 cmH ₂ O/60 l/min Expiratory limb: < 2.3 cmH ₂ O/60 l/min Neonate circuit (10 mm ID, flow of 5 l/min.): Inspiratory limb: < 6 cmH ₂ O/5l/min Expiratory limb: < 6 cmH ₂ O/5l/min
Compliance ¹	Adult circuit (19 mm ID): Approximately 2 ml/cmH ₂ O Pediatric circuit (15 mm ID): Approximately 1.9 ml/cmH ₂ O Coaxial circuit : Approximately 0.64 ml/cmH ₂ O Neonate circuit : Approximately 1.0 ml/cmH ₂ O
Volume ¹	Adult circuit (19 mm ID): Approximately 2.4 l Pediatric circuit (15 mm ID): Approximately 1.8 l Flow Sensor: 9 ml (single-use) or 11 ml (reusable) Neonate circuit (10 mm ID): Approximately 0.9 l Flow Sensor: Approximately 1.3 ml
Bacteria filter	Particle size: Captures particles of 0.3 mm (micron) with > 99.99% efficiency Resistance: < 2 cmH ₂ O at 60 l/min
Flow Sensor dead space	< 1.3 ml (neonates) < 9 ml (adult/pediatric)

1. The inspiratory limb includes ambient valve, Flow Sensor, inspiratory filter, inspiratory tubes, and humidifier. It does not include the heating wire. The expiratory limb includes expiratory tubes, water trap, expiratory valve, and Flow Sensor.

A.10 Other technical data

Table A-16 lists other ventilator technical data.

Table A-16. Other technical data

Parameter	Specification
Patient ideal body weight (determined from Pat. height setting)	0.2 to 139 kg (6.6 to 306 lb) ¹
Inspiratory pressure	0 to 60 cmH ₂ O
Maximum limited pressure	60 cmH ₂ O
Maximum working pressure	0 to 60 cmH ₂ O (a combination of PEEP/CPAP and Pinsp). Ensured through pressure limiting.
Maximum inspiratory flow	240 l/min (150 l/min with 100% O ₂)
Tidal volume/target tidal volume	20 to 2000 ml
Minute volume capability	Up to 60 l/min
Inspiratory time (spontaneous breaths)	0.2 to 3 s
Minimum expiratory time	20% of cycle time; 0.2 s to 0.8 s
Inspiratory valve response time	< 13 ms
Automatic expiratory base flow	4 to 20 l/min For Flowtrigger ≤ 2 l/min: 4 l/min For Flowtrigger > 2 l/min: 2 x Flowtrigger
Means of inspiratory triggering	Flow (Flowtrigger control setting)
Oxygen mixer accuracy	± (volume fraction of 2.5% + 2.5% of actual reading)

Table A-16. Other technical data

Parameter	Specification
Measuring and display devices	Pressure and volume measurements: Type: Differential pressure transducer, variable orifice Sensing position: Patient Y-piece Measurements: See Table A-9
	Time measurements: Type: Microprocessor Sensing position: Inside ventilator Measurements: See Table A-9
	Oxygen measurement: Type: Galvanic cell Sensing position: Inspiratory pneumatics- Measurement: Delivered oxygen concentration, range: 18 to 103% Response time: < 12 s to reach 90% of final oxygen concentration Initialization time (time from switching on until operating performance): < 40 s
	Display of settings, alarms, and monitored data: Type: TFT color Size: 640 x 480 pixels, 10.4 in. (264 mm) diagonal
Oxygen cell life	1 year or 5000 h nominal. Actual cell life depends on operating environment. Operation at higher temperatures or higher oxygen concentrations shortens cell life.
Alarm loudness	50 to 65dB(A) at 1 m
Tests and special functions	Tightness test, oxygen cell calibration, Flow Sensor calibration, 100% O ₂ , manual breath, inspiratory hold maneuver, nebulization (30 min, 8 l/min), communications interface, compensation of breathing circuit resistance and compliance.

1. Actual patient weight can be much greater (e.g., 300 kg or 661 lb)

A.11 Standards and approvals

The HAMILTON-C2 was developed in accordance with pertinent international standards and FDA guidelines.

The ventilator is manufactured within an EN ISO 13485 and EN ISO 9001, Council Directive 93/42/EEC, Annex II, Article 1 certified quality management system.

The ventilator meets the Essential Requirements of Council Directive 93/42/EEC. It is a class IIb device.

The ventilator meets relevant parts of the following standards:

- **IEC 60601-1:** Medical electrical equipment, Part 1: General requirements for safety. The device classification is: Class II, Type B applied part (ventilator breathing system, VBS), type BF applied part (CO₂ sensor including CO₂ module connector), ordinary enclosed equipment without protection against ingress of liquids, continuous operation
- **IEC 60601-1-2:** Medical electrical equipment: General requirements for safety - Collateral standard: Electromagnetic compatibility. Requirements and tests
- **IEC 60601-2-12:** Medical electrical equipment: Particular requirements for the safety of lung ventilators - Critical care ventilators
- **EN 794-1:** Lung ventilators. Particular requirements for critical care ventilators
- **CAN/CSA-C22.2 No. 601.1:** Medical electrical equipment: General requirements for safety
- **UL 60601-1:** Medical electrical equipment: General requirements for safety

A.12 EMC declarations (IEC 60601-1-2)

The HAMILTON-C2 ventilator is intended for use in the electromagnetic environment specified in Table A-17 through Table A-19. The customer or the user of the HAMILTON-C2 ventilator should ensure that it is used in such an environment.

The HAMILTON-C2 is intended for use in an electromagnetic environment in which radiated RF disturbances are controlled. The customer or the user of the HAMILTON-C2 can help prevent electromagnetic interference by maintaining a minimum distance between portable and mobile RF communications equipment (transmitters) and the HAMILTON-C2 as recommended in Table A-19, according to the maximum output power of the communications equipment.

Table A-17. Guidance and manufacturer's declaration – electromagnetic emissions

Emissions test	Compliance	Electromagnetic environment - guidance
RF emissions CISPR 11	Group 1	The HAMILTON-C2 ventilator uses RF energy only for its internal function. Therefore, its RF emissions are very low and are not likely to cause any interference in nearby electronic equipment.
RF emissions CISPR 11	Class A	The HAMILTON-C2 ventilator is suitable for use in all establishments other than domestic and those directly connected to the public low-voltage power supply network that supplies buildings for domestic purposes.
Harmonic emissions IEC 61000-3-2	Class A	
Voltage fluctuations/ flicker emissions IEC 61000-3-3	Complies	

Table A-18. Guidance and manufacturer's declaration – electromagnetic immunity¹

Immunity test	IEC 60601-1-2 test level	Compliance level	Electromagnetic environment – guidance
Electrostatic discharge (ESD) IEC 61000-4-2	±6 kV contact ±8 kV air	±6 kV contact ±8 kV air	Floors should be wood, concrete, or ceramic tile. If floors are covered with synthetic material, the relative humidity should be at least 30%.
Electrical fast transient/burst IEC 61000-4-4	±2 kV for power supply lines ±1 kV for input/output lines	±2 kV for power supply lines ±1 kV for input/output lines	Mains power quality should be that of a typical commercial or hospital environment.
Surge IEC 61000-4-5	±1 kV line(s) to line(s) ±2 kV line(s) to earth	±1 kV line(s) to line(s) ±2 kV (line(s) to earth	Mains power quality should be that of a typical commercial or hospital environment.
Voltage dips, short interruptions, and voltage variations on power supply input lines IEC 61000-4-11	< 5% UT ¹ (>95% dip in UT) for 0.5 cycle 40% UT ¹ (60% dip in UT) for 5 cycles 70% UT ¹ (30% dip in UT) for 25% UT (>95% dip in UT) for 5 s	<5% UT ¹ (>95% dip in UT) for 0.5 cycle 40% UT ¹ (60% dip in UT) for 5 cycles 70% UT ¹ (30% dip in UT) for 25 cycles <5% U(>95% dip in UT) for 5 s	Mains power quality should be that of a typical commercial or hospital environment.

Table A-18. Guidance and manufacturer's declaration – electromagnetic immunity¹

Immunity test	IEC 60601-1-2 test level	Compliance level	Electromagnetic environment – guidance
Power frequency (50/60 Hz) magnetic field IEC 61000-4-8	3 A/m	30 A/m	The power frequency magnetic field should be at levels characteristic of a typical location in a typical commercial or hospital environment.
Conducted RF IEC 61 000-4-6	3 Vrms 150 kHz to 80 MHz outside ISM bands ² 10 Vrms 150 kHz to 80 MHz in ISM bands ⁴	10 Vrms 10 Vrms	Portable and mobile RF communications equipment should be used no closer to any part of the HAMILTON-C2 ventilator, including cables, than the recommended separation distance calculated from the equation applicable to the frequency of the transmitter. Recommended separation distance: $d = 0.35 \sqrt{P}$ $d = 1.2 \sqrt{P}$

Table A-18. Guidance and manufacturer's declaration – electromagnetic immunity¹

Immunity test	IEC 60601-1-2 test level	Compliance level	Electromagnetic environment – guidance
Radiated RF IEC 61000-4-3	10 V/m 80 MHz to 2.5 GHz	20 V/m	80 MHz to 800 MHz $d = 0.6 \sqrt{P}$ 800 MHz to 2.5 GHz $d = 1.15 \sqrt{P}$ where P is the maximum output power rating of the transmitter in watts (W) according to the transmitter manufacturer and d is the recommended separation distance in meters (m).³ Field strengths from fixed RF transmitters, as determined by an electromagnetic site survey⁴, should be less than the compliance level in each frequency range⁵. Interference may occur in the vicinity of equipment marked with the symbol 

1. UT is the AC mains voltage prior to application of the test level.
2. The ISM (industrial, scientific and medical) bands between 150 kHz and 80 MHz are 6.765 MHz to 6.795 MHz; 13.553 MHz to 13.567 MHz; 26.957 MHz to 27.283 MHz; and 40.66 MHz to 40.70 MHz.
3. The compliance levels in the ISM frequency bands between 150 kHz and 80 MHz and in the frequency range 80 MHz to 2.5 GHz are intended to decrease the likelihood that mobile/portable communications equipment could cause interference if it is inadvertently brought into patient areas. For this reason, an additional factor of 10/3 is used in calculating the recommended separation distance for transmitters in these frequency ranges.

4. Field strengths from fixed transmitters, such as base stations for radio (cellular/cordless) telephones and land mobile radios, amateur radio, AM and FM radio broadcast and TV broadcast cannot be predicted theoretically with accuracy. To assess the electromagnetic environment due to fixed RF transmitters, an electromagnetic site survey should be considered. If the measured field strength in the location in which the HAMILTON-C2 ventilator is used exceeds the applicable RF compliance level above, the HAMILTON-C2 ventilator should be observed to verify normal operation. If abnormal performance is observed, additional measures may be necessary, such as re-orienting or relocating the HAMILTON-C2 ventilator.
5. Over the frequency range 150 kHz to 80 MHz, field strengths should be less than 3 V/m.

Table A-19. Recommended separation distances between portable and mobile RF communications equipment and the HAMILTON-C2 ventilator¹

Rated maximum output power of transmitter (W)	Separation distance according to frequency of transmitter (m) ²³⁴⁵			
	150 kHz to 80 MHz outside ISM bands d = 0.35√P	150 kHz to 80 MHz in ISM bands d = 1.2√P	80 MHz to 800 MHz d = 0.6√P	800 MHz to 2.5 GHz d = 1.15√P
0.01	0.035	0.12	0.06	0.12
0.1	0.11	0.38	0.19	0.36
1	0.35	1.2	0.6	1.15
10	1.1	3.8	1.9	3.6
100	3.5	12	6	11.5

1. These guidelines may not apply in all situations. Electromagnetic propagation is affected by absorption and reflection from structures, objects, and people.
2. For transmitters rated at a maximum output power not listed above, the recommended separation distance d in meters (m) can be determined using the equation applicable to the frequency of the transmitter, where P is the maximum output power rating of the transmitter in watts (W) according to the transmitter manufacturer.
3. At 80 MHz and 800 MHz, the separation distance for the higher frequency range applies.
4. The ISM (industrial, scientific and medical) bands between 150 kHz and 80 MHz are 6.765 MHz to 6.795 MHz; 13.553 MHz to 13.567 MHz; 26.957 MHz to 27.283 MHz; and 40.66 MHz to 40.70 MHz.

5. An additional factor of 10/3 is used in calculating the recommended separation distance for transmitters in the ISM frequency bands between 150 kHz and 80 MHz and in the frequency range 80 MHz to 2.5 GHz to decrease the likelihood that mobile/portable communications equipment could cause interference if it is inadvertently brought into patient areas.

A.13 Warranty

LIMITED WARRANTY

THE WARRANTY DESCRIBED IN THIS AGREEMENT IS IN LIEU OF ANY AND ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, INCLUDING IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. HOWEVER, IMPLIED WARRANTIES ARE NOT DISCLAIMED DURING THE PERIOD OF THIS LIMITED WARRANTY.

HAMILTON MEDICAL guarantees its products to be shipped free from defects in material and workmanship.

The warranty does not include disposable items. Disposable items and consumable products are considered to be of single use or of limited use only and must be replaced regularly as required for proper operation of the product following the operator's manual.

HAMILTON MEDICAL and the manufacturer shall have no obligations nor liabilities in connection with the product other than what is specified herein, including without limitation, obligations and/or liabilities for alleged negligence, or for strict liability. In no event shall the company be liable for incidental or consequential damages, either direct or contingent.

This Limited Warranty shall be void and not apply:

1. If the product has not been installed and connected by an authorized local representative of HAMILTON MEDICAL in accordance with the instructions furnished by HAMILTON MEDICAL and by a HAMILTON MEDICAL representative;
2. If replacements and/or repairs have not been performed by authorized or properly trained personnel.
3. If no evidence is present that the occurrence of damage/repair happened within the certified warranty period;

-
4. If the serial number has been altered, effaced or removed and there is no bill of sale or evidence to verify the product's purchase date;
 5. If the defects arise from misuse, negligence, or accidents or from repair, adjustment, modification or replacement made outside HAMILTON MEDICAL's factories or other than an authorized service center or authorized service representative;
 6. If the product has been modified, or in any nature altered without prior written authorization from HAMILTON MEDICAL.

Replacements and/or repairs furnished under this Limited Warranty do not carry a new warranty, but carry only the unexpired portion of the original Limited Warranty. The warranty of repaired and/or replaced components does not exceed the Limited Warranty of the device.

To obtain service under this Limited Warranty, claimant must promptly notify the country's sales partner of HAMILTON MEDICAL regarding the nature of the problem, serial number and the date of purchase of the Product.

Except as stated above, HAMILTON MEDICAL shall not be liable for any damages, claims or liabilities including, but not limited to, personal bodily injury, or incidental, consequential, or special damages.

A.14 Miscellaneous

The general terms and conditions of HAMILTON MEDICAL shall be applicable. This agreement shall be governed by and construed in accordance with the laws of Switzerland and may be enforced by either party under the jurisdiction of the court of Chur, Switzerland.

B Modes of ventilation

B.1	Introduction	B-2
B.2	The biphasic concept	B-5
B.3	Mandatory modes	B-8
	B.3.1 (S)CMV+ mode or APVcmv	B-8
	B.3.2 PCV+ mode	B-11
B.4	Spontaneous modes (SPONT and NIV)	B-13
B.5	SIMV modes	B-19
	B.5.1 SIMV+ mode or APVsimv	B-20
	B.5.2 PSIMV+ and NIV-ST modes	B-23
B.6	nCPAP-PS mode	B-28
	B.6.1 Introduction	B-28
	B.6.2 Controls of nCPAP-PS	B-30
B.7	DuoPAP (Duo positive airway pressure)	B-31
	B.7.1 Introduction	B-31
	B.7.2 The many faces of DuoPAP	B-32
	B.7.3 Pressure support in DuoPAP breaths	B-33
	B.7.4 Synchronization	B-34
	B.7.5 Controls of DuoPAP	B-34
B.8	APRV (Airway pressure release ventilation)	B-36
	B.8.1 Introduction	B-36
	B.8.2 Initialization of APRV	B-37
	B.8.3 Sustained high pressure recruitment manoeuvres	B-39
	B.8.4 Controls of APRV	B-39
B.9	SAFETY mode and ambient state	B-41

B.1 Introduction

This section discusses the principles of operation for the HAMILTON-C2 ventilation modes. It lays the groundwork by describing the biphasic concept, which is at the heart of the device's pneumatic design and which is vital to understanding how the HAMILTON-C2 ventilates in all modes.

The HAMILTON-C2 has a full range of ventilation modes that provide full and partial ventilatory support. Table B-1 classifies these modes according to a scheme developed by Branson et al¹. The table classifies modes based on primary breath type and characteristics of mandatory breaths in that mode. Table A-7 lists the controls active in all modes.

Volume modes in the HAMILTON-C2 are delivered by an adaptive volume controller. Combining the advantages of pressure-controlled ventilation with volume-targeted ventilation, the adaptive volume controller ensures that the target tidal volume is delivered but without undue application of pressure, even when lung characteristics change. The operation of the adaptive volume controller is described as part of the (S)CMV+ mode description, Section B-3.

The HAMILTON-C2 modes have these general characteristics:

- **Mandatory breaths.** See Table B-1 for information on mandatory breaths as they apply to the various modes. Not listed in the table are operator-initiated mandatory (manual) breaths, which are pressure controlled and time cycled. Mandatory breaths have a decelerating flow waveform.
- **Spontaneous breaths.** Spontaneous breathing is allowed in all modes at any time. Additionally, -in all modes except (S)CMV+, PVC+ and APRV- spontaneous breaths are pressure supported and time cycled if the users set flow trigger threshold is passed. In the modes (S)CMV+ and PCV+, a spontaneous effort of the patient activating the flow trigger, results in a pressure controlled and time cycled breath.

1. Branson RD, Hess DR, Chatburn RL. Respiratory Care Equipment. Philadelphia: Lippincott Williams & Wilkins Publishers, 1999;359-93.

- **Triggering.** Breaths can be patient (flow) triggered in all modes, based on an operator-set flow sensitivity. All modes permit operator-initiated manual breaths.
- **Pressure.** A positive baseline pressure (PEEP/CPAP) may be set for all breaths in all modes.
- **Pressure rise time.** An operator-set pressure ramp (P-ramp) defines the time required for inspiratory pressure to rise to the set (target) pressure.
- **FiO₂.** FiO₂ can be set in all modes except when oxygen is provided by a low-pressure supply.

Table B-1. Classification of HAMILTON-C2 ventilation modes

Mode name	Breathing pattern ¹	Mandatory breaths			
		Control type ²	Trigger ³	Limit ⁴	Cycle ⁵
PCV+	PC-CMV	Setpoint	F, T	P	T
	Operational logic: Every breath is pressure controlled and mandatory.				
PSIMV+	PC-IMV	Setpoint	F, T	P	T, F
	Operational logic: Mandatory breaths are pressure controlled.				
SPONT	PC-CSV	Setpoint	F	P	F
	Operational logic: Every breath is spontaneous.				
(S)CMV+	PC-CMV	Adaptive	F, T	V, P	T
	Operational logic: Every breath is volume targeted and mandatory.				
SIMV+	PC-IMV	Adaptive	F, T	V, P	T
	Operational logic: Mandatory breaths are volume targeted.				
nCPAP-PS	PC-IMV	Setpoint	F, T	P	T, F
	Operational logic: Mandatory breaths are pressure controlled. Leakage is compensated for.				

Table B-1. Classification of HAMILTON-C2 ventilation modes

Mode name	Breathing pattern ¹	Mandatory breaths			
		Control type ²	Trigger ³	Limit ⁴	Cycle ⁵
NIV	PC-CSV	Setpoint	F	P	F
	Operational logic: Every breath is spontaneous. Leakage is compensated for.				
NIV-ST	PC-IMV	Setpoint	F, T	P	T, F
	Operational logic: Mandatory breaths are pressure controlled. Leakage is compensated for.				
DuoPAP	PC-IMV	Setpoint	F, T	P	F, T
	Operational logic: Mandatory breaths are pressure controlled. Leakage is compensated for.				
APRV	PC-APRV	Setpoint	T	P	T
	Every breath is pressure controlled and mandatory.				

1. A designator that combines the primary control variable (PC = pressure control) for the mandatory breaths (or in CSV, for the spontaneous breaths) with the breath sequence (CMV = continuous mandatory ventilation – all breaths are mandatory, IMV = intermittent mandatory ventilation – spontaneous breaths between mandatory breaths, CSV = continuous spontaneous ventilation – all breaths are spontaneous). The control variable is the independent variable that the ventilator manipulates to cause inspiration.
2. The way pressure and volume are controlled within or between breaths. Setpoint means the ventilator output automatically matches a constant, unvarying, operator preset input value (like the production of a constant inspiratory pressure or tidal volume from breath to breath). Optimum is a control scheme that uses automatic adjustment of setpoints to optimize other variables as respiratory mechanics change. Adaptive control means one setpoint (e.g., the pressure limit) of the ventilator is automatically adjusted over several breaths to maintain another setpoint (e.g., the target tidal volume) as the mechanics of the respiratory system change.
3. A trigger variable starts inspiration.
4. A limit variable can reach and maintain a preset level before inspiration ends but it does not end inspiration.
5. A cycle variable is a measured parameter used to end inspiration.

B.2 The biphasic concept

It is widely accepted that early spontaneous breathing is beneficial for many ventilated patients, provided the device lets the patient inspire and exhale whenever the respiratory muscles contract and relax. In other words, the ventilator needs to be in synchrony with the patient's muscle contractions, regardless of how the ventilator's controls are set.

Accordingly, the HAMILTON-C2's pneumatics were designed to permit the patient's free spontaneous breathing. The ventilator never forces the patient into a preset breathing pattern but always yields to spontaneous breathing. This is achieved through a special valve control system independent of any trigger mechanism. This concept is called "biphasic," because gas can flow into and out of the patient at any time. The biphasic concept applies in all HAMILTON-C2 ventilation modes.

Implementation of the biphasic concept improves patient breathing comfort¹, as spontaneous breathing is encouraged², less sedation is required even with prolonged inspiratory phases³, and there is a free delivery of flow to the patient at any time. The decelerating inspiratory waveform improves gas distribution, oxygenation, and lowers peak pressures^{2,3,4,5,6}.

1. 1996 Mar;153(3):1025-33

2. Kuhlen R, Putensen C, Editorial: Maintaining spontaneous breathing efforts during mechanical ventilatory support, *Int Care Med* 1999;25:1203-5

3. Sydow M, Burchardi H, Ephraim E, Zielmann S, Crozier TA, Long-term effects of two different ventilatory modes on oxygenation in acute lung injury. Comparison of airway pressure release ventilation and volume-controlled inverse ratio ventilation. *Am J Respir Crit Care Med* 1994 Jun;149(6):1550-6

4. Al-Saady N, Bennett ED, Decelerating inspiratory flow waveform improves lung mechanics and gas exchange in patients on intermittent positive pressure ventilation. *Int Care Med* 1985;11(2):68-75

5. Tharatt R St, Allen RP, Albertson TE, Pressure controlled inverse ratio ventilation in severe adult respiratory failure, *Chest* 1988 Oct;94(4):755-62

Figure B-1 through Figure B-3 illustrate this concept. Figure B-1 shows a passive patient ventilated by pressure-controlled ventilation. Gas flows into the patient when pressure rises and gas flows out of the patient when inspiratory pressure falls.

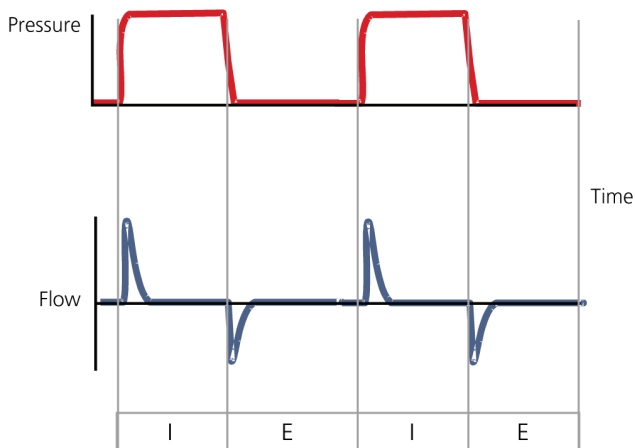


Figure B-1. Conventional pressure-controlled ventilation in a passive patient. Flow to patient during inspiration (I); flow from patient during expiration (E) only.

Figure B-2 shows a partially active patient during conventional pressure-controlled ventilation when the trigger is disabled. If respiratory activity is present during the machine-determined inspiratory phase, gas flows only into the patient. Gas flow out of the patient is impossible due to the closed expiratory valve (see Flow curve).

-
6. Davis K Jr, Branson RD, Campbell RS, Porembka DT, Comparison of volume and pressure control ventilation: is flow waveform the difference? J Trauma 1996 Nov;41(5):808-14

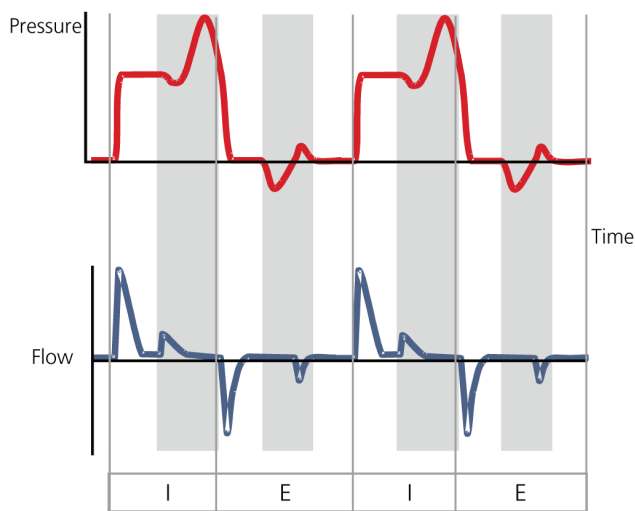


Figure B-2. Conventional pressure-controlled ventilation in an active patient when the trigger is off. Pressure increases when the patient tries to exhale (E) and pressure decreases when the patient tries to inspire (I), as valves are closed.

During the machine-determined expiratory phase, gas flows only out of the patient. Gas flow to the patient is impossible due to the closed inspiratory valve (see Flow curve).

Figure B-2 shows a partially active patient in the HAMILTON-C2's biphasic PCV+ mode. Note that inspiration and exhalation are possible at any time, thereby offering the best synchronization possible between patient and machine. PCV+ acts like an artificial atmosphere to the patient: the machine varies the airway pressure to guarantee a minimal ventilation and the patient contributes whatever they can.

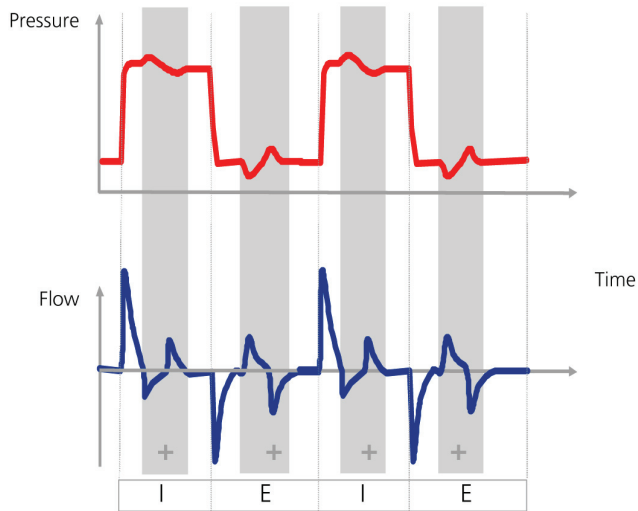


Figure B-3. Biphasic PCV+ in an active patient when trigger is off. The patient can freely inspire and exhale during any phase of ventilation (+).

B.3 Mandatory modes

The mandatory ventilation modes, (S)CMV+ and PCV+, deliver time-cycled mandatory breaths.

B.3.1 (S)CMV+ mode or APVcmv

The (S)CMV+ (synchronized controlled mandatory ventilation) mode provides volume-targeted mandatory breaths using an adaptive volume controller. The adaptive volume controller delivers the set target volume (V_t) at the lowest possible pressure, depending on lung conditions.

The control settings active in the (S)CMV+ mode are shown in Figure B-4 and Figure B-5. The tidal volume (V_t) setting defines the delivered volume. The Rate and I:E control settings determine the breath timing. Breaths can be triggered by the ventilator, patient, or user.

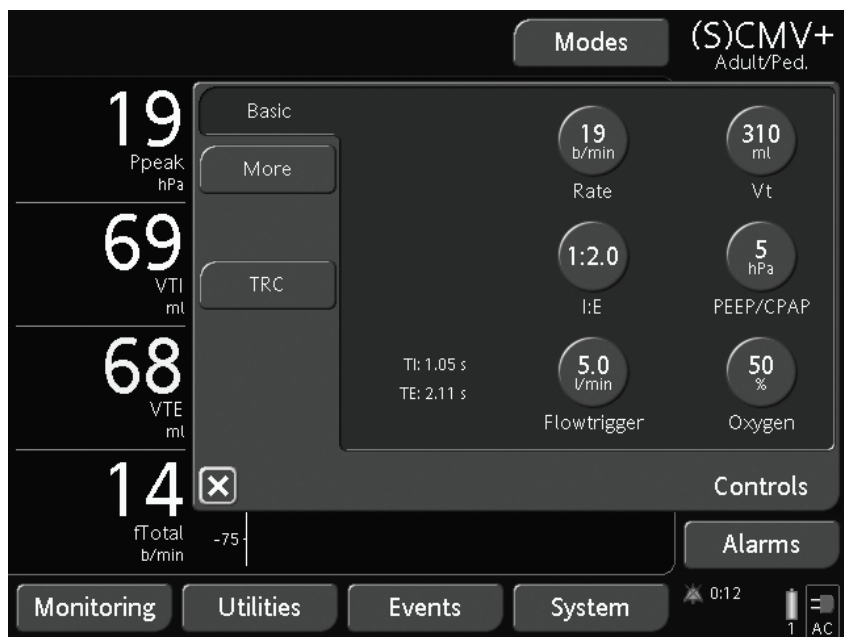


Figure B-4. (S)CMV+ basic controls

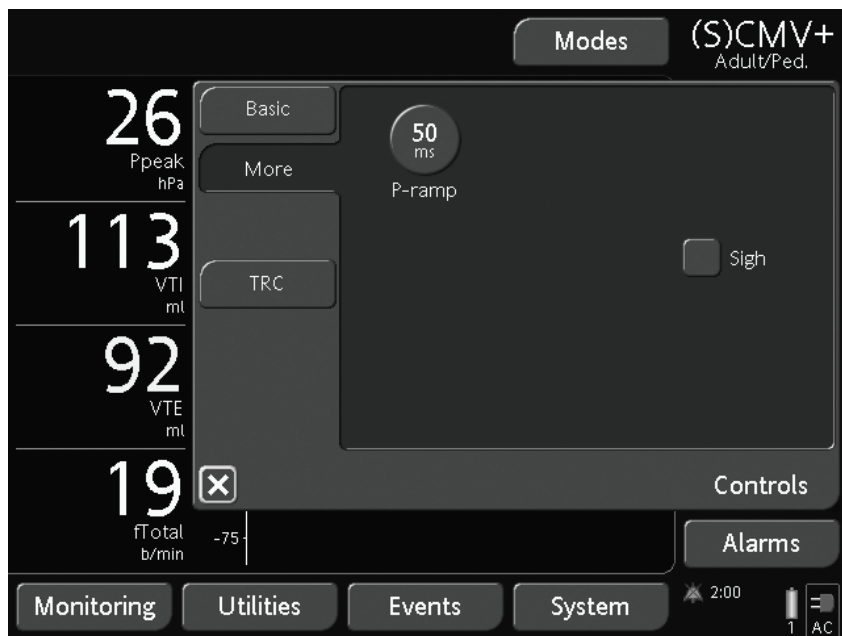


Figure B-5. (S)CMV+ more controls

The adaptive volume controller works by comparing the user-set tidal volume with the average of delivered and exhaled tidal volumes. The controller in turn adjusts the inspiratory pressure that will be applied during the next breath in order to obtain the target volume. The inspiratory pressure is adjusted in steps, to a maximum of 2 cmH₂O per breath. The controller adjusts the total inspiratory pressure applied (including PEEP) so it is between (PEEP + 5 cmH₂O) and (Pressure - 10 cmH₂O), to a maximum of 60 cmH₂O (Figure B-6).

The ventilator recalculates the minimal inspiratory pressure needed to achieve the target volume as lung characteristics change. This continuous reassessment of the patient's dynamic lung status helps guarantee the required ventilation while preventing hypoventilation or barotrauma.

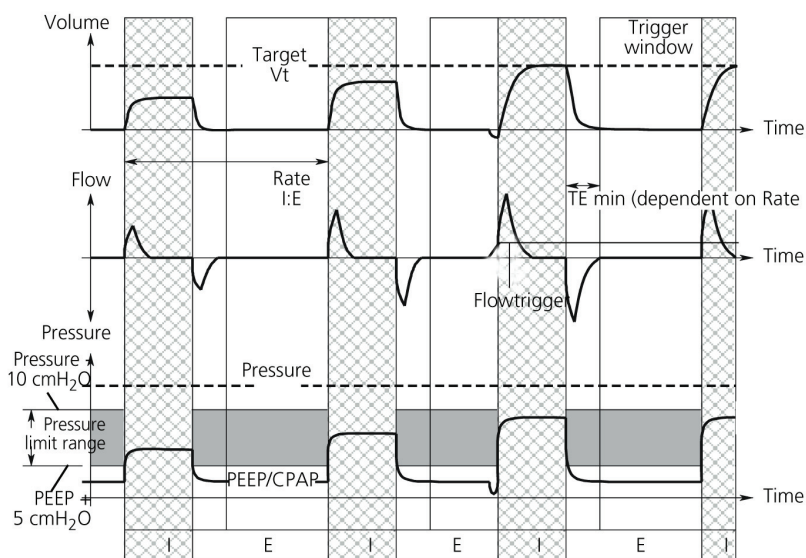


Figure B-6. Breath delivery by the adaptive volume controller

B.3.2 PCV+ mode

The PCV+ (pressure-controlled ventilation) mode provides pressure-controlled mandatory breaths. The mode's biphasic nature allows free breathing at both the PEEP and the Pcontrol pressure levels.

The control settings active in the PCV+ mode are shown in Figure B-7 through Figure B-8. The pressure control (Pcontrol) setting defines the applied pressure. The Rate and I:E control settings determine the breath timing. Breaths can be triggered by the ventilator, patient, or user.

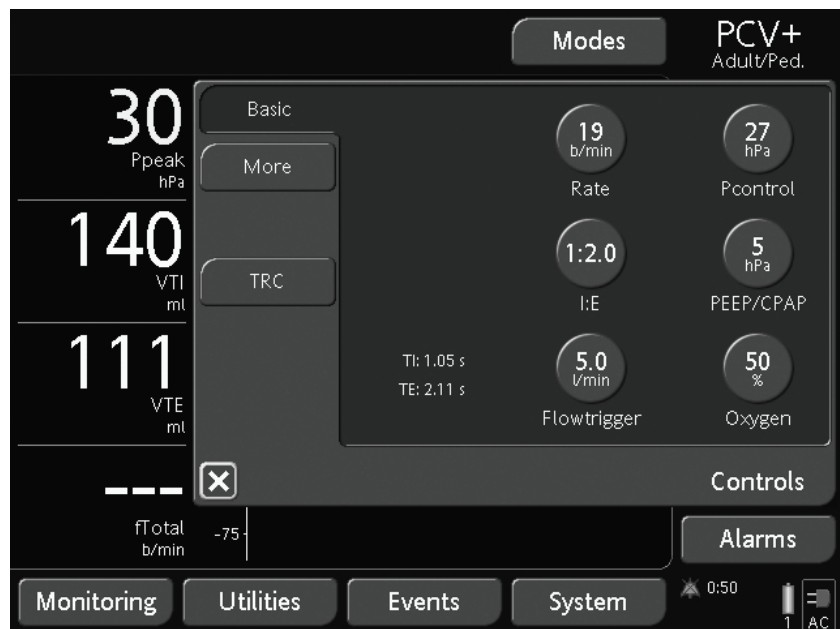


Figure B-7. PCV+ basic controls

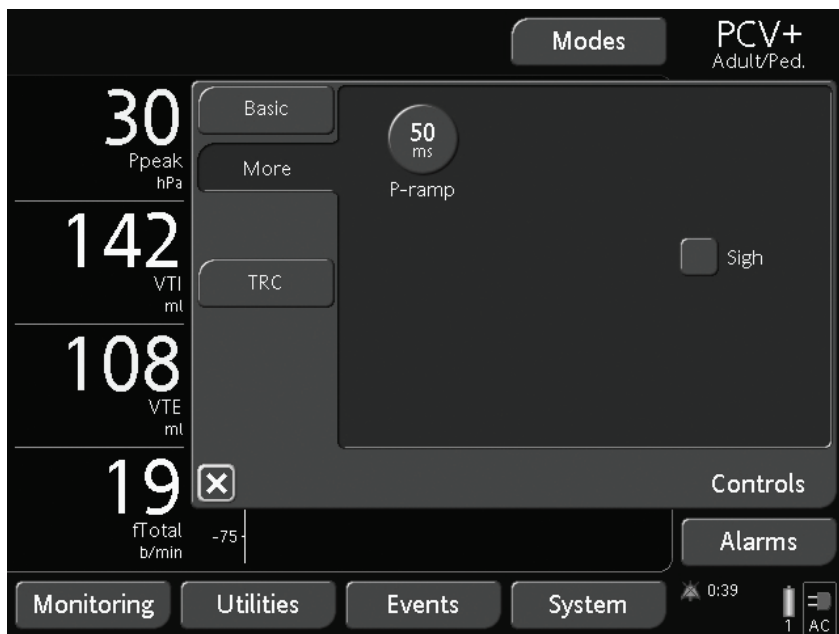


Figure B-8. PCV+ more controls

B.4 Spontaneous modes (SPONT and NIV)

The spontaneous or pressure support modes, SPONT and NIV (noninvasive ventilation), deliver spontaneous breaths and user-initiated manual (mandatory) breaths. SPONT is designed for an intubated patient, while NIV is designed for use with a mask or other noninvasive patient interface. See Appendix D for clinical application information on the noninvasive modes. In SPONT and NIV, the ventilator functions as a demand flow system. The patient's spontaneous breathing efforts can also be supported with the set pressure support. When pressure support is set to zero, the ventilator functions like a conventional CPAP system.

The control settings active in the SPONT mode are shown in Figure B-9 through Figure B-11. The control settings active in the NIV mode are shown in Figure B-12 through Figure B-14. The pressure support (Psupport) setting defines the applied pressure. The patient determines the breath timing. Breaths can be triggered by the patient or user.

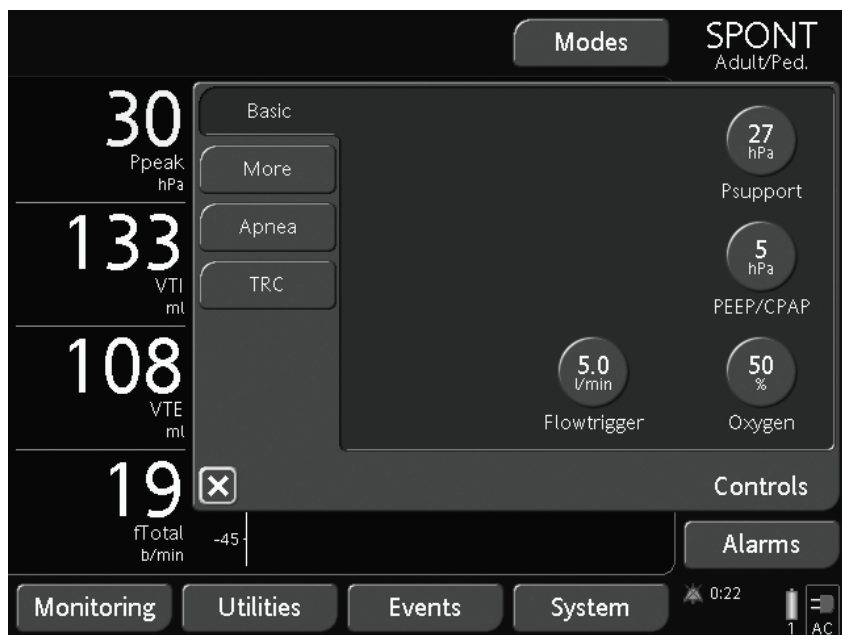


Figure B-9. SPONT basic controls

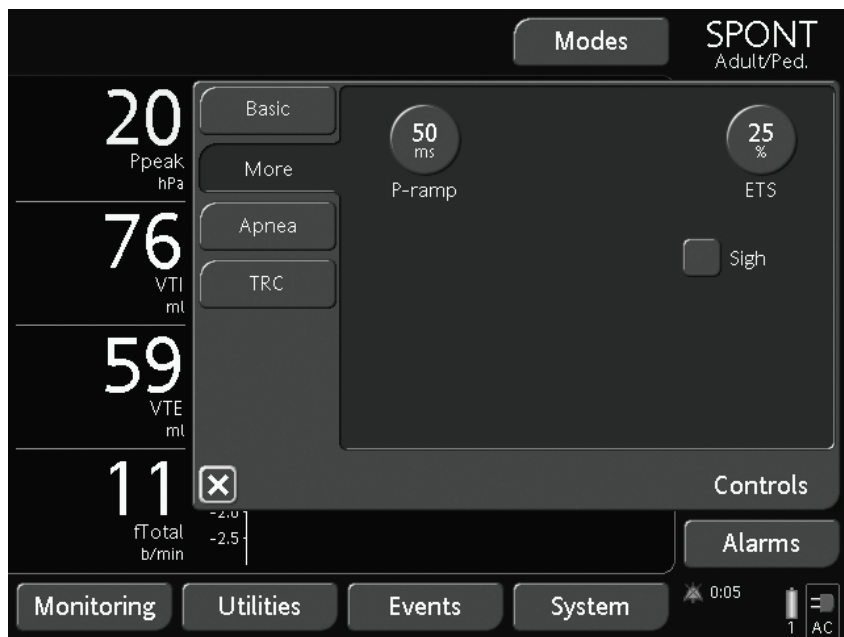


Figure B-10. SPONT more controls

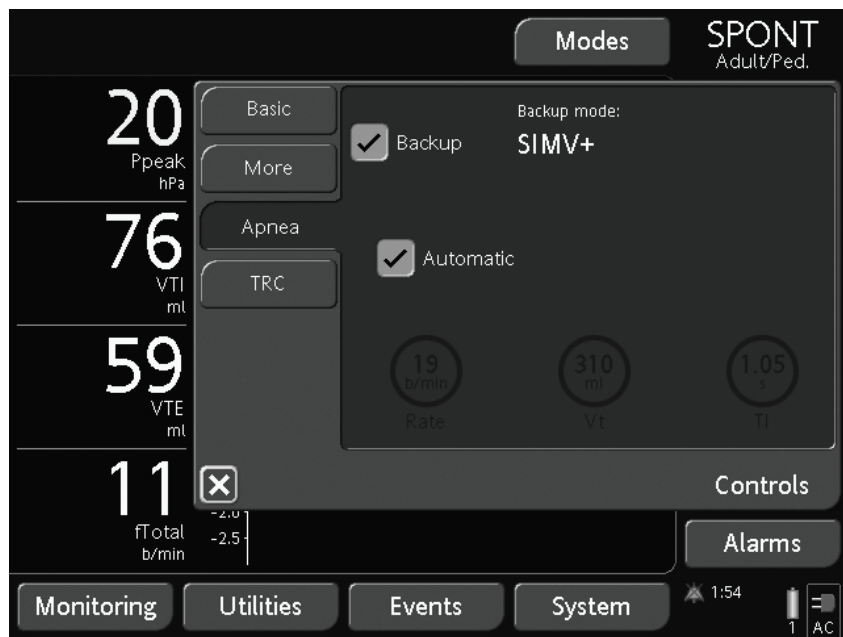


Figure B-11. SPONT apnea controls

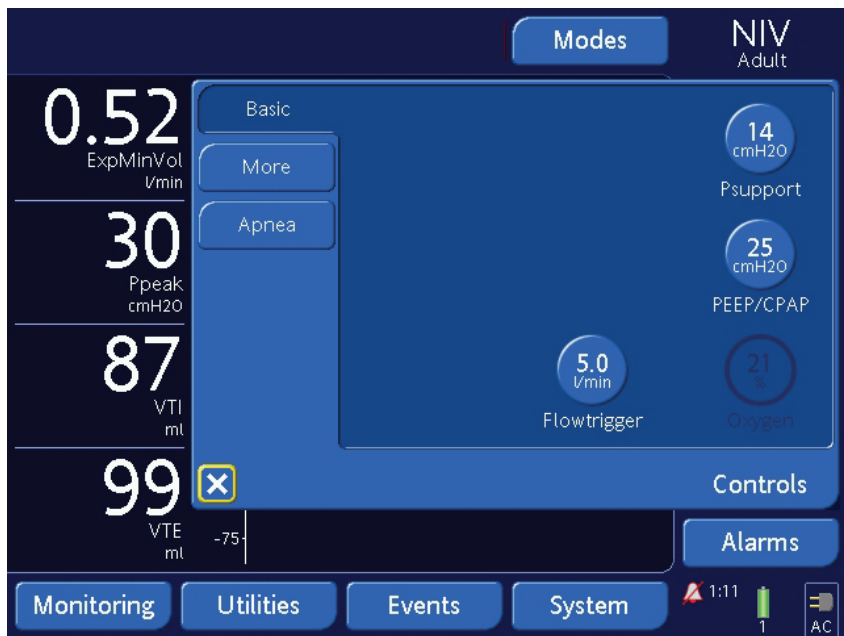


Figure B-12. NIV basic controls



Figure B-13. NIV more controls

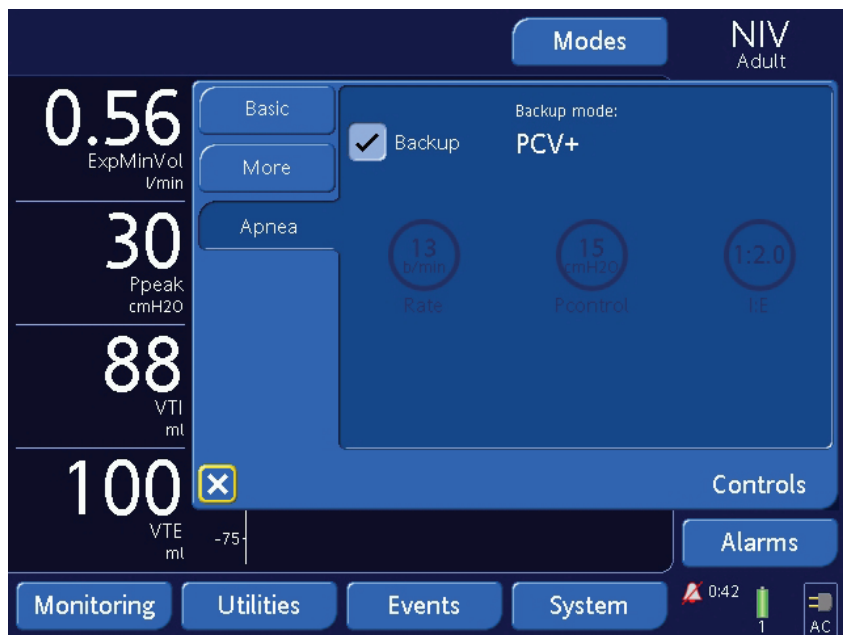


Figure B-14. NIV apnea controls

B.5 SIMV modes

The HAMILTON-C2's SIMV (synchronized intermittent mandatory ventilation) modes, SIMV+, PSIMV+, and NIV-ST, guarantee breath delivery at the user-set Rate. Both mandatory and spontaneous breaths may be delivered in the SIMV modes. Because the SIMV modes are mixed modes, with attributes of both a mandatory and a spontaneous pressure support mode, the user sets the parameters specific to the applicable mandatory mode and to the spontaneous mode.

B.5.1 SIMV+ mode or APVsimv

The SIMV+ mode combines attributes of the (S)CMV+ and SPONT modes, delivering volume-targeted, time-cycled mandatory breaths and pressure-supported, flow-cycled spontaneous breaths. As with the (S)CMV+ mode, the SIMV+ mode ensures that the set target volume is delivered during the mandatory breaths.

Each SIMV+ breath interval, t_{imv} , can be thought of as having a trigger window, $t_{trigger}$, during which the ventilator waits for a patient trigger (Figure B-15). If the patient triggers a breath during this time, the ventilator immediately delivers a mandatory breath with the target volume. If the patient does not trigger a breath, then the ventilator automatically delivers a mandatory breath at the end of $t_{trigger}$. After the mandatory breath is delivered, the patient is free to take any number of spontaneous breaths for the remainder of t_{imv} .

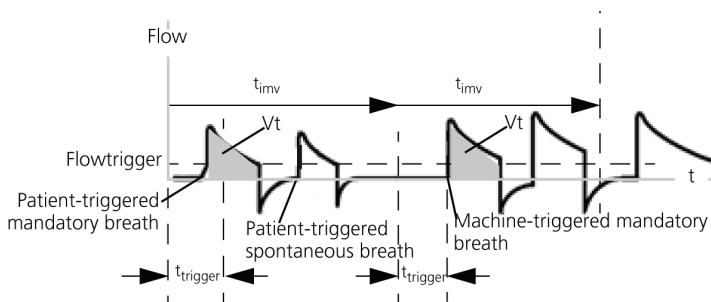


Figure B-15. Breath timing in SIMV+

The control settings active in the SIMV+ mode are shown in Figure B-16 through Figure B-18. The SIMV+ mode requires that you set the parameters needed for both mandatory and spontaneous breath types. As for (S)CMV+ breaths, the tidal volume (V_t) setting defines the delivered volume of mandatory breaths. The Rate and TI control settings define the breath timing. For spontaneous breaths, the expiratory trigger sensitivity (ETS) setting defines the percentage of peak flow that cycles the HAMILTON-C2 into exhalation. Breaths can be triggered by the ventilator, patient, or user.



Figure B-16. SIMV+ basic controls

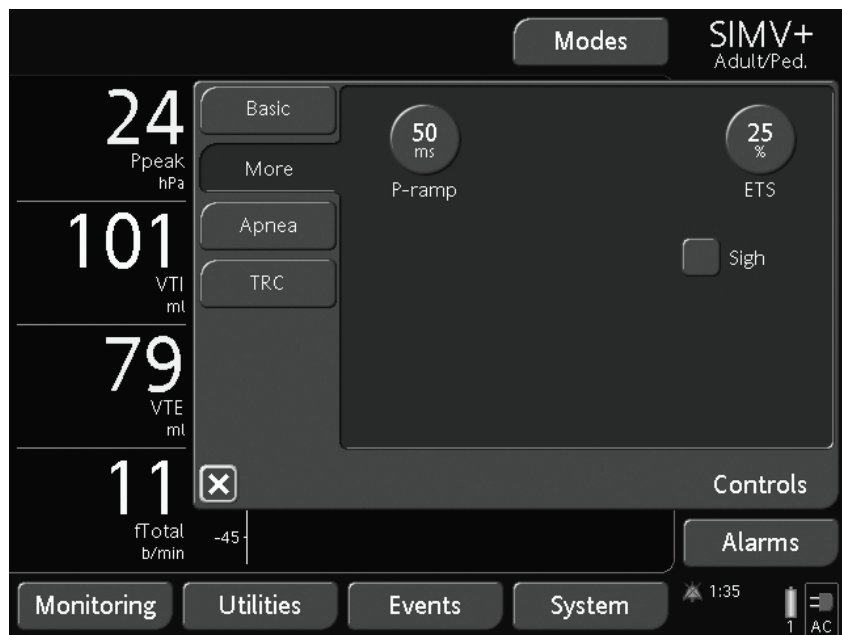


Figure B-17. SIMV+ more controls

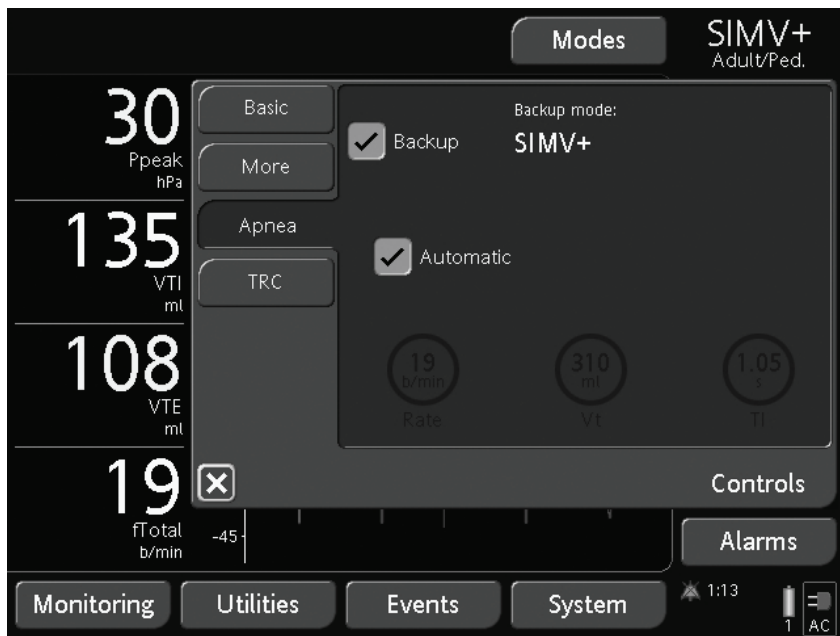


Figure B-18. SIMV+ apnea controls

B.5.2 PSIMV+ and NIV-ST modes

The PSIMV+ (pressure-controlled SIMV) and NIV-ST (spontaneous/timed noninvasive ventilation) modes deliver pressure-controlled, time-cycled mandatory breaths and pressure-supported, flow-cycled spontaneous breaths. PSIMV+ combines attributes of the PCV+ and SPONT modes, while NIV-ST combines attributes of the PCV+ and NIV modes. SIMV+, like SPONT, is designed for an intubated patient, while NIV-ST, like NIV, is designed for use with a mask or other noninvasive patient interface. See Appendix D for clinical application information on the noninvasive modes.

As with the PCV+ mode, PSIMV+ and NIV-ST both deliver a preset pressure, but do not guarantee a fixed tidal volume, especially during changes in respiratory system compliance, airway resistance, AutoPEEP, or the patient's respiratory activity.

If the patient triggers a breath during a portion of the breath interval we'll call t_{imv} , the ventilator immediately delivers a spontaneous breath (Figure B-19). If the patient does not trigger an inspiration during this time, the ventilator initiates a mandatory breath at the end of t_{imv} .

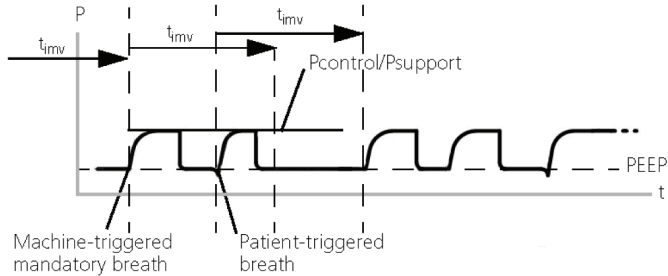


Figure B-19. Breath timing in PSIMV+ and NIV-ST

The control settings active in the PSIMV+ mode are shown in Figure B-20 and Figure B-21. The control settings active in the NIV-ST mode are shown in Figure B-22 and Figure B-23. Both modes require that you set the parameters needed for both mandatory and spontaneous breath types. The inspiratory pressure (P_{insp}) setting defines the applied pressure for both mandatory and spontaneous breaths. The Rate and TI (inspiratory time) control settings define the breath timing. For spontaneous breaths, the expiratory trigger sensitivity (ETS) setting defines the percentage of peak flow that cycles the HAMILTON-C2 into exhalation. Breaths can be triggered by the ventilator, patient, or user.

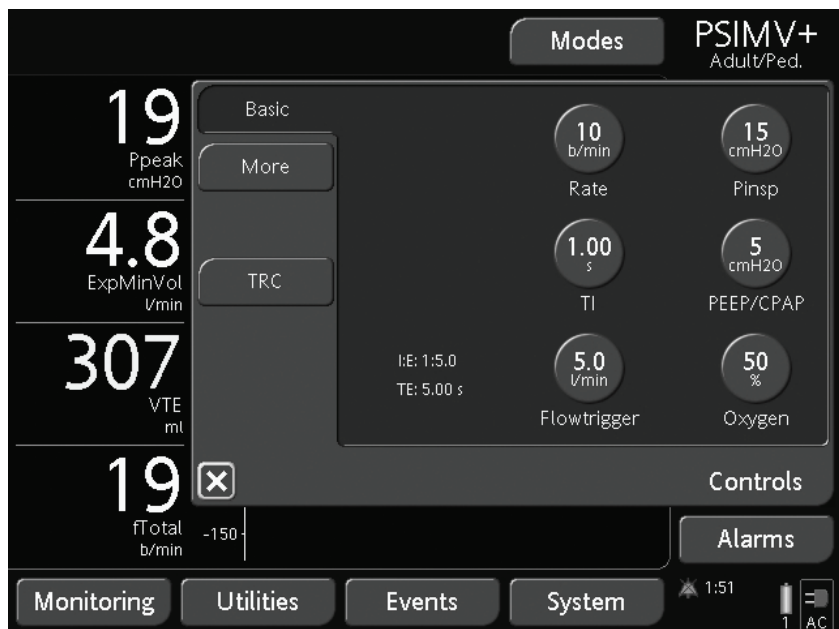


Figure B-20. PSIMV+ basic controls

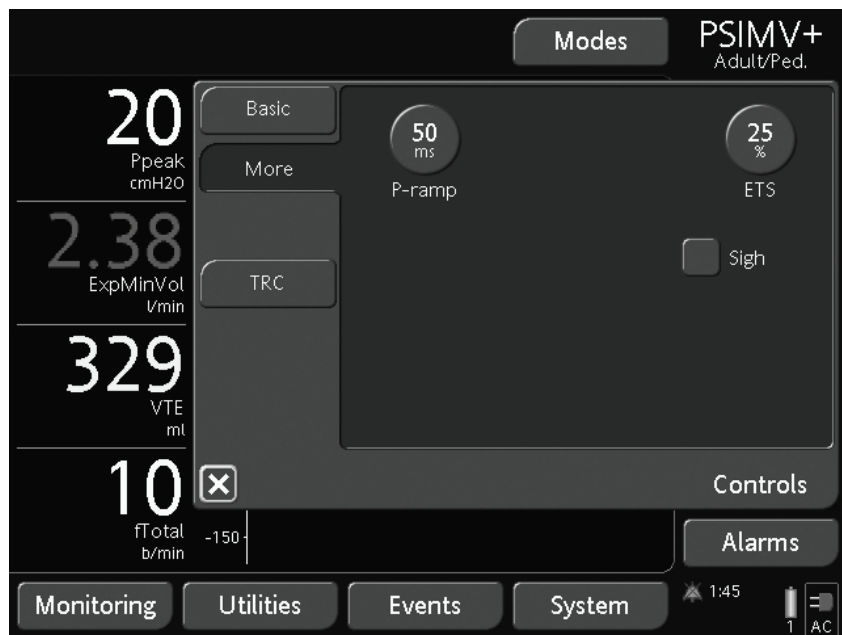


Figure B-21. PSIMV+ more controls



Figure B-22. NIV-ST basic controls

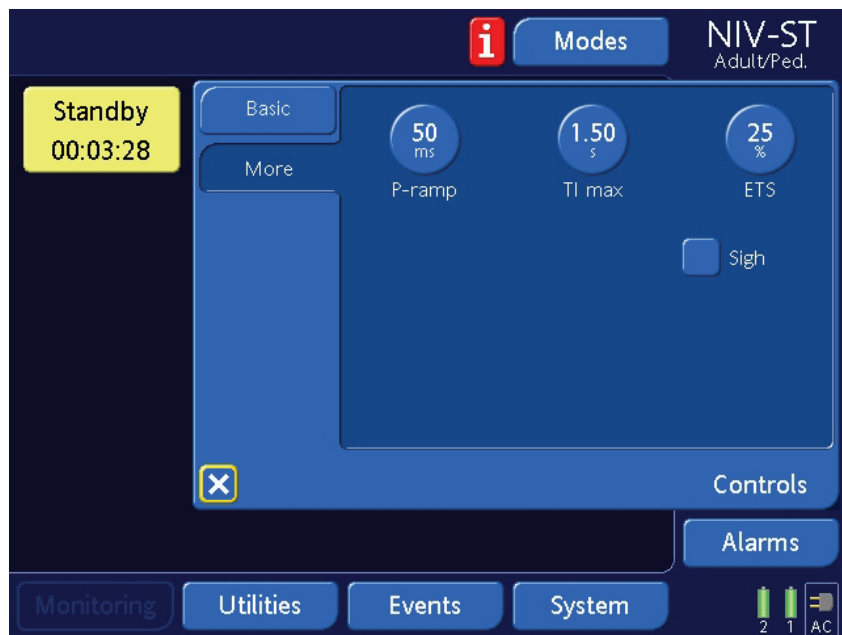


Figure B-23. NIV-ST more controls

B.6 nCPAP-PS mode

B.6.1 Introduction

NOTE:

- For nCPAP-PS the position of the Flow Sensor is at the expiratory valve. The correct set-up is shown in Figure 2-5.
 - To perform flow sensor calibration, position the flow sensor proximal to the patient as usual.
-

The nCPAP-PS (nasal Continuous Positive Airway Pressure - Pressure Support) mode is designed to apply CPAP and intermittent positive pressure support over a nasal interface (mask or prongs). The pressure support P_{insp} can alternatively be set to zero. In this case, the patient's oxygenation is fostered over the PEEP and the FiO_2 . Ventilation is performed by the patient by inhalation and exhalation from the baseflow.

As with the PSIMV+ mode nCPAP-PS delivers a preset pressure P_{insp} , but does not guarantee a fixed tidal volume, especially during changes in respiratory system compliance, airway resistance, AutoPEEP, or the patient's respiratory activity.

If the patient triggers a breath during a portion of the breath interval we will call t_{imv} , the ventilator immediately delivers a spontaneous breath (Figure B-24). If the patient does not trigger an inspiration during this time, the ventilator initiates a mandatory breath at the end of t_{imv} .

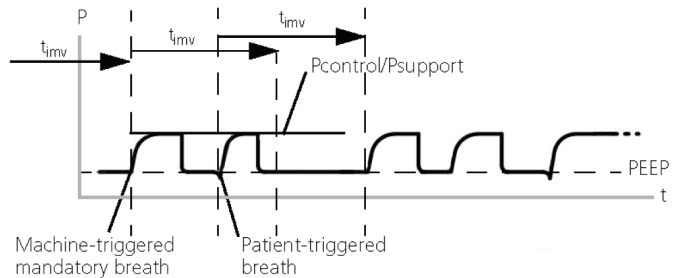


Figure B-24. Breath timing in nCPAP-PS

The control settings active in the nCPAP-PS mode are shown in Figure B-25 and Figure B-26. The mode requires that you set the parameters needed for both mandatory and spontaneous breath types. The inspiratory pressure (P_{insp}) setting defines the applied pressure for both mandatory and spontaneous breaths. The Rate and TI (inspiratory time) control settings define the breath timing. For spontaneous breaths, the expiratory trigger sensitivity (ETS) setting defines the percentage of peak flow that cycles the HAMILTON-C2 into exhalation. Breaths can be triggered by the ventilator, patient, or user.

The nCPAP-PS system is integrated with a nasal cannula with interchangeable silicone prongs (size marked), a Delivery Circuit (heated wire) and Cap (see separate instruction leaflet).

B.6.2 Controls of nCPAP-PS

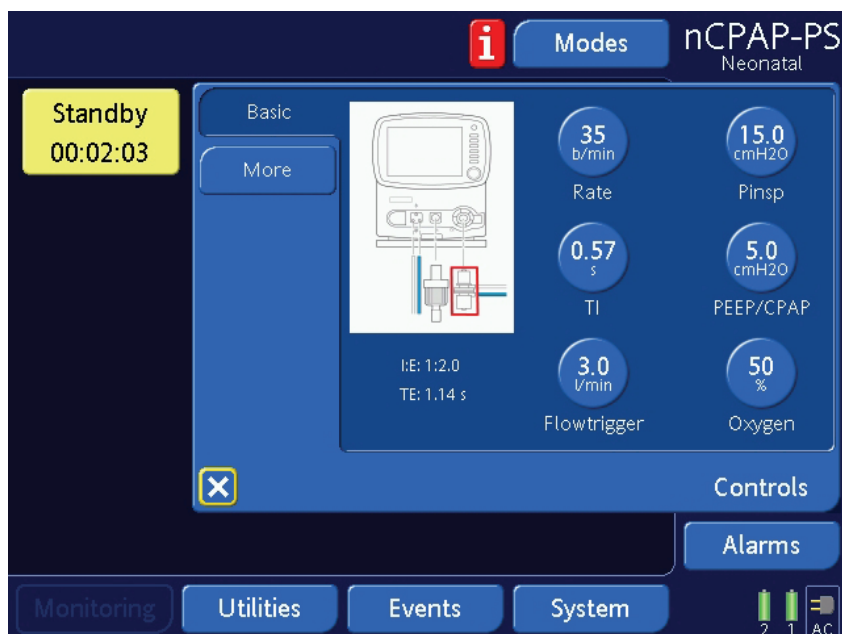


Figure B-25. nCPAP-PS basic controls

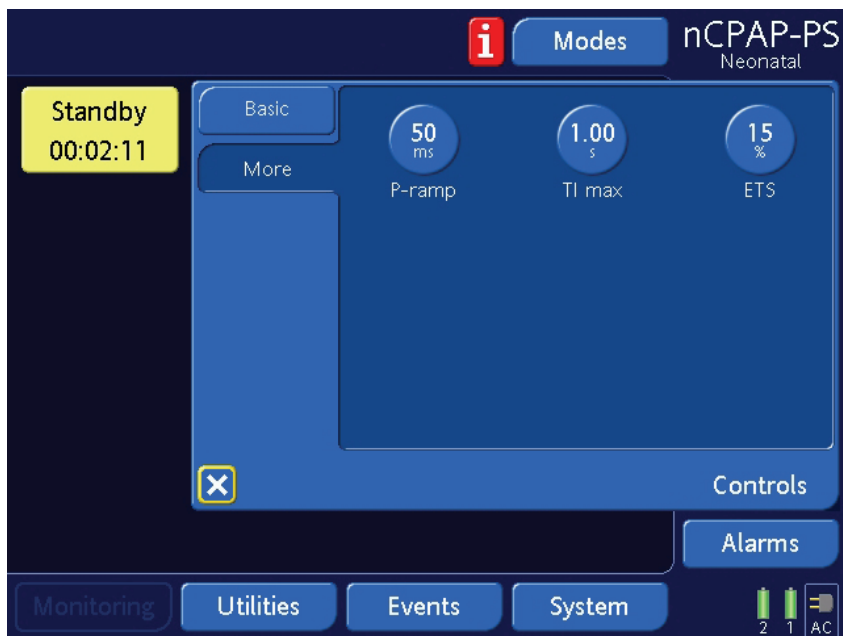


Figure B-26. nCPAP-PS more controls

B.7 DuoPAP (Duo positive airway pressure)

B.7.1 Introduction

DuoPAP is a related form of pressure ventilation designed to support spontaneous breathing on two alternating levels of CPAP. In these mode, the ventilator switches automatically and regularly between two operator-selected levels of positive airway pressure or CPAP. The patient may breathe freely at either level. In DuoPAP pressure support can be added to these spontaneous breaths. Cycling between the levels is triggered by DuoPAP timing settings or by patient effort. Pressure/time curve for this mode is shown in Figure B-27.

The control settings active in the DuoPAP mode are shown in Figure B-29 until Figure B-31.

In DuoPAP (Figure B-27), the switchover between the two levels is defined by pressure settings P_{high} and PEEP/CPAP and time settings T_{high} and Rate. Like PEEP/CPAP, P_{high} is relative to atmospheric pressure.

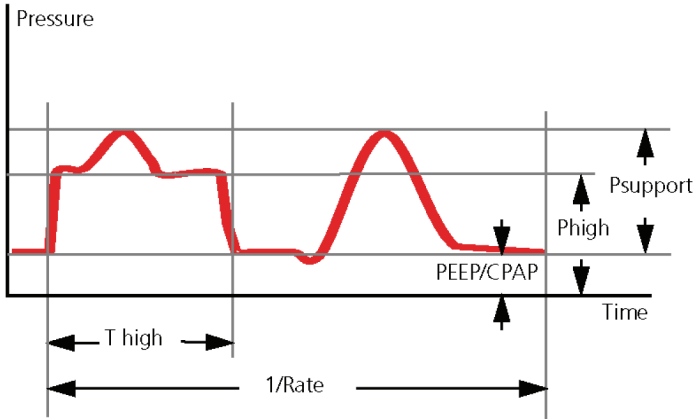


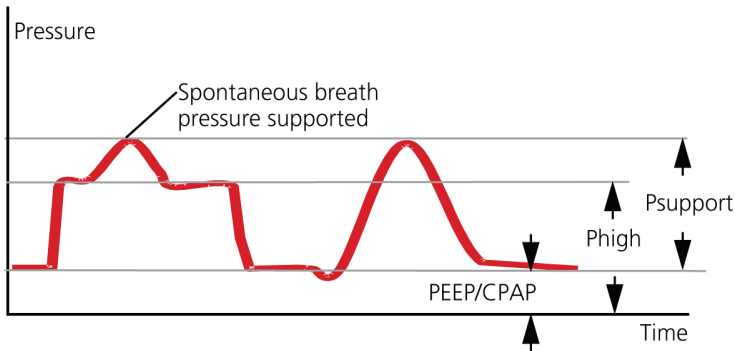
Figure B-27. DuoPAP pressure curve

B.7.2 The many faces of DuoPAP

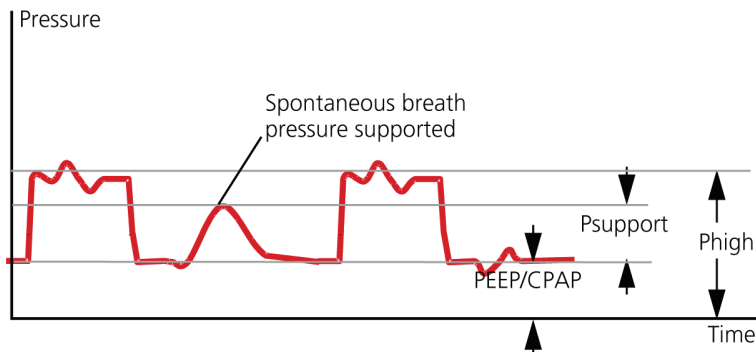
With different patients and with different combinations of control settings, DuoPAP can be made to resemble a variety of conventional ventilation modes. At conventional settings and in the absence of spontaneous breathing, DuoPAP resembles PCV+. As you decrease the rate, keeping T_{high} short relative to the time at the lower pressure level, the modes look more like PSIMV+, with spontaneous breaths following mandatory breaths. If t_{high} almost set to breath cycle time with just enough time at the low level to allow full or near-full exhalation, these mode looks like APRV. By setting PEEP/CPAP and P_{high} equal to one another and adjusting other parameters, the mode can be made to resemble SPONT.

B.7.3 Pressure support in DuoPAP breaths

Pressure support can be set to assist spontaneous breaths in DuoPAP, whether they occur at the PEEP/CPAP or Phigh level. Psupport is set relative to PEEP/CPAP the target pressure becomes PEEP/CPAP. That means that spontaneous breaths at the Phigh level are supported only when this target pressure is greater than Phigh. Figure B-28 (a) shows the situation where breaths at both the PEEP and Phigh level are pressure-supported. Figure B-28 (b) shows the situation where only breaths at the PEEP/CPAP level are pressure-supported.



a. All spontaneous breaths pressure supported



b. Only spontaneous breaths at PEEP/CPAP pressure supported

Figure B-28. Pressure support in DuoPAP

B.7.4 Synchronization

To adapt easily to the patient's spontaneous breathing pattern, the change-overs from low to high pressure level and vice versa are synchronized with the patient's spontaneous breathing.

The frequency of the change-over is kept constant, even with patient synchronization, by defining a trigger time window with a fixed time constant.

B.7.5 Controls of DuoPAP



Figure B-29. DuoPAP basic controls

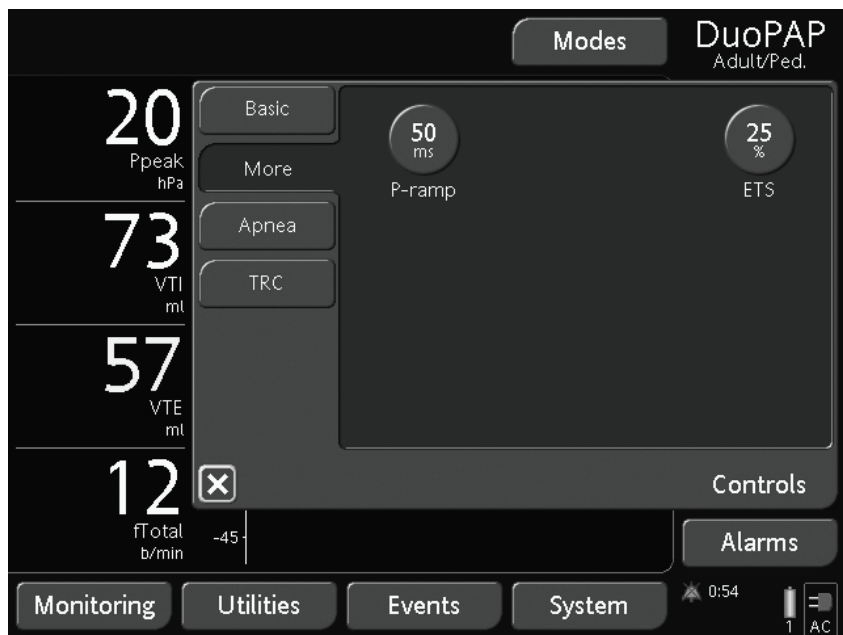


Figure B-30. DuoPAP more controls

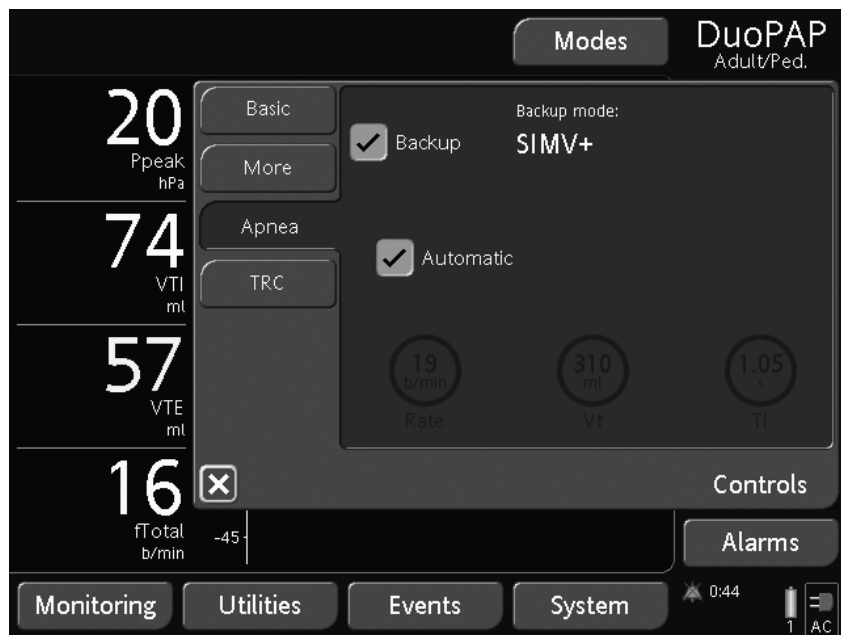


Figure B-31. DuoPAP apnea controls

B.8 APRV (Airway pressure release ventilation)

B.8.1 Introduction

APRV produces alveolar ventilation as an adjunct to CPAP. Set airway pressure P_{high} is transiently released to a lower level P_{low} , after which it is quickly restored to reinflate the lungs. For a patient who has no spontaneous breathing efforts, APRV is similar to pressure-controlled inverse ratio ventilation.

APRV allows spontaneous breathing at any time during the respiratory cycle.

V_t for APRV breath depends on lung compliance, respiratory resistance, the magnitude and duration of the pressure release and the magnitude of the patient's spontaneous breathing efforts.

Figure B-32 shows the breath timing and pressure settings in APRV.

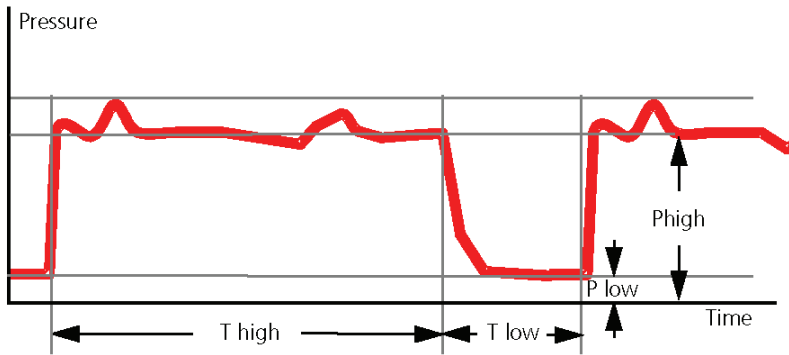


Figure B-32. APRV breath timing

B.8.2 Initialization of APRV

NOTE:

When applying long Thigh phases without patient activity, you may adjust the apnea time alarm setting to avoid switching to apnea backup ventilation.

When switching to APRV the first time, timing and pressure settings proposed are based on Table B-2. Settings for Phigh, Thigh and Tlow will be stored when switching back to another mode, but recalled when returning to APRV again.

The initialization occurs as in Table B-2 shown or last set value in APRV.

Table B-2. Control parameters for initialization of APRV¹

IBW (kg)	Phigh (mbar)²	Thigh (s)	Tlow (s)
0.2 to 3	20	1.4	0.2
3 to 5	20	1.7	0.3
6 to 8	20	2.1	0.3
9 to 11	20	2.6	0.4
12 to 14	20	2.6	0.4
15 to 17	20	2.6	0.4
18 to 20	20	2.6	0.4
21 to 23	20	3.5	0.5
24 to 26	20	3.5	0.5
27 to 29	20	3.5	0.5
30 to 39	20	3.5	0.5
40 to 49	20	4.4	0.6
50 to 59	20	4.4	0.6
60 to 69	20	5.4	0.6
70 to 79	20	5.4	0.6
80 to 89	20	5.4	0.6
90 to 99	23	5.4	0.6
≥ 100	25	5.4	0.6

1. When switching to APRV a second time (repeatedly) the former settings are kept.

2. Plow = 5 mbar

B.8.3 Sustained high pressure recruitment manoeuvres

One approach to lung recruitment has been that of sustained high pressure recruitment manoeuvres. APRV can be set to apply elevated pressures for up to 40 seconds.

B.8.4 Controls of APRV

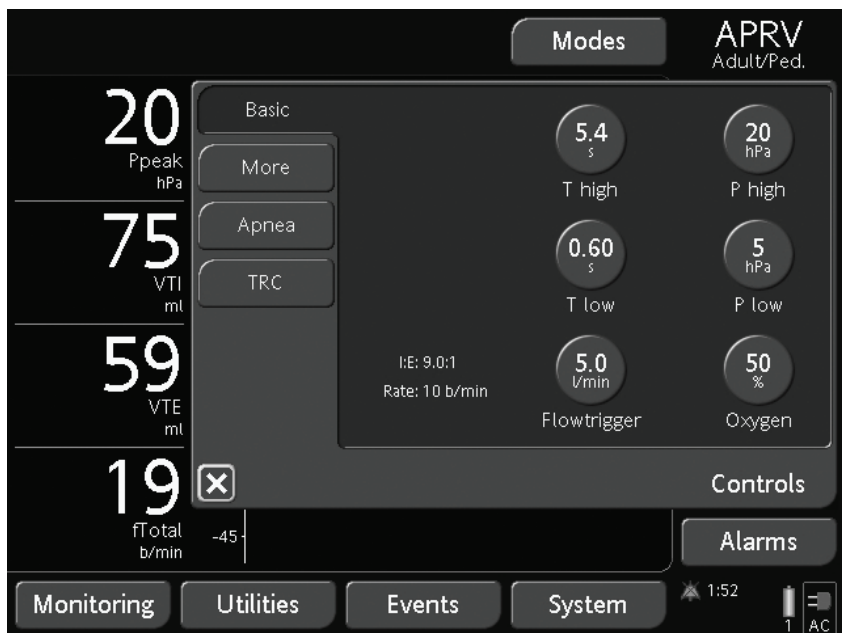


Figure B-33. APRV basic controls

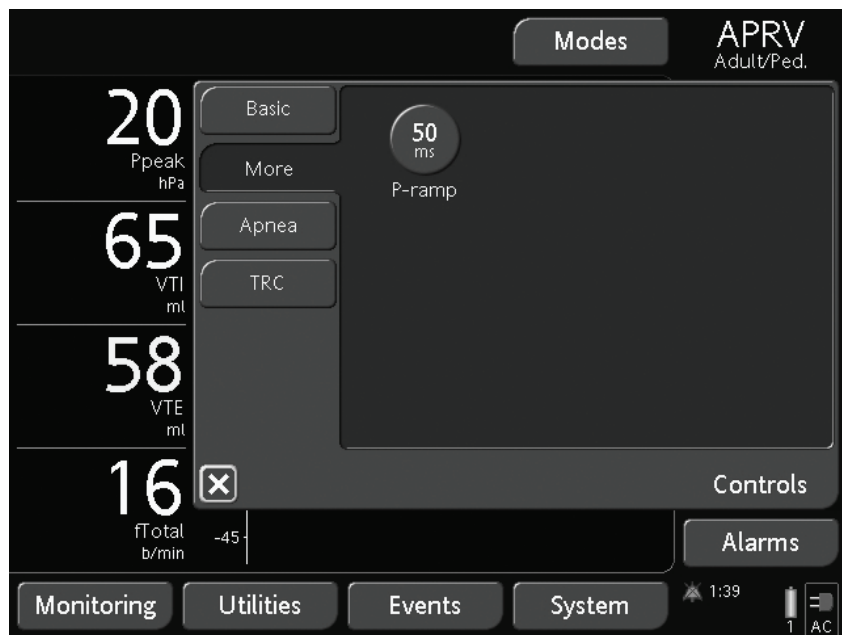


Figure B-34. APRV more controls

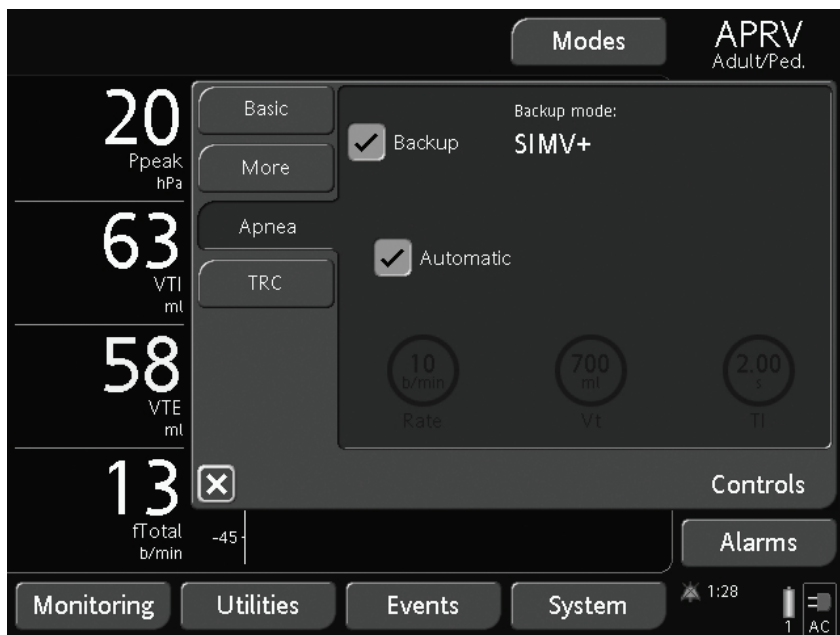


Figure B-35. APRV apnea controls

B.9 SAFETY mode and ambient state

In case of some technical failure the HAMILTON-C2 switches to SAFETY mode. This gives the user time for corrective actions, such as organizing a replacement ventilator.

The turbine runs constant to create P_{insp} (Table B-3). The expiratory valve switches system pressure levels between PEEP and inspiratory pressure. Patient sensing is nonfunctional during safety ventilation. You must switch off ventilator power to exit safety ventilation.

If the technical fault alarm is serious enough to possibly compromise safe ventilation, the ventilator enters the ambient state. The inspiratory valve is closed and the ambient and expiratory valves are opened, letting the patient breathe room air unassisted. You must switch off ventilator power to exit the ambient state.



Figure B-36. Display SAFETY mode

Table B-3. Safety mode settings

IBW (kg)	Pinsp (cmH₂O)	Rate (b/min)	I:E	PEEP¹	O2
< 3	15	≤ 35	1:2		> 21 %
3 to 5	15	30	1:2		> 21 %
6 to 8	15	25	1:2		> 21 %
9 to 11	15	20	1:2		> 21 %
12 to 14	15	20	1:2		> 21 %
15 to 20	15	20	1:2		> 21 %
21 to 23	15	15	1:2		> 21 %
24 to 29	15	15	1:2		> 21 %
30 to 39	15	14	1:2		> 21 %
40 to 59	15	12	1:2		> 21 %
60 to 89	15	10	1:2		> 21 %
90 to 99	18	10	1:2		> 21 %
≥ 100	20	10	1:2		> 21 %

1. Set PEEP plus circuit resistance (+ 5 cmH₂O).

APPENDIX **C** ASV (adaptive support ventilation)

C.1	Introduction	C-2
C.2	ASV use in clinical practice	C-3
C.3	Detailed functional description of ASV	C-15
C.3.1	Normal minute ventilation	C-15
C.3.2	Targeted minute ventilation	C-16
C.3.3	Lung-protective rules strategy	C-17
C.3.4	Optimal breath pattern	C-20
C.3.5	Dynamic adjustment of lung protection	C-24
C.3.6	Dynamic adjustment of optimal breath pattern	C-25
C.4	Minimum work of breathing (Otis' equation)	C-26
C.5	ASV technical data	C-28
C.6	ASV Start up	C-31
C.7	References	C-32

C.1 Introduction

WARNING

This appendix describes ASV as it is implemented in the Hamilton-S1 device. It does not replace the clinical judgment of a physician and is not to be used for clinical decision making.

In 1977, Hewlett et al. introduced mandatory minute volume (MMV). "The basic concept is that the system is supplied with a metered, preselected minute volume of fresh gas, from which the patient breathes as much as he is able, the remainder being delivered to him via a ventilator. Thus the patient is obliged to breathe, one way or the other, a Mandatory Minute Volume MMV" (Hewlett 1977).

Since then, many ventilators have included versions of MMV under different names. However, all commercially available MMV algorithms have clear limitations, which lead to certain risks for the patient (Quan 1990). These include rapid shallow breathing, inadvertent PEEP creation, excessive dead space ventilation, and inadvertent wrong operator settings due to very complicated use.

Adaptive Support Ventilation (ASV) was designed to minimize those risks and limitations. ASV maintains an operator-preset, minimum minute ventilation independent of the patient's activity. The target breathing pattern (tidal volume and rate) is calculated using Otis' equation, based on the assumption that if the optimal breath pattern results in the least work of breathing, it also results in the least amount of ventilator-applied inspiratory pressure when the patient is passive. Inspiratory pressure and machine rate are then adjusted to meet the targets. A lung protection strategy ensures ASV's safety. In contrast to MMV, ASV attempts to guide the patient using a favorable breathing pattern and avoids potentially detrimental patterns like rapid shallow breathing, excessive dead space ventilation, breath stacking (inadvertent PEEP), and excessively large breaths.

Contrary to some opinions, ASV does not eliminate the need for a physician or clinician. However, ASV alleviates the need for tedious tasks and laborious readjustments of the ventilator; thus, it is a modern tool for the clinician. As such, ASV does not make clinical decisions. ASV executes a general command from the clinician and the clinician can modify it. This command can be summarized, where the modifiable parts are in bold:

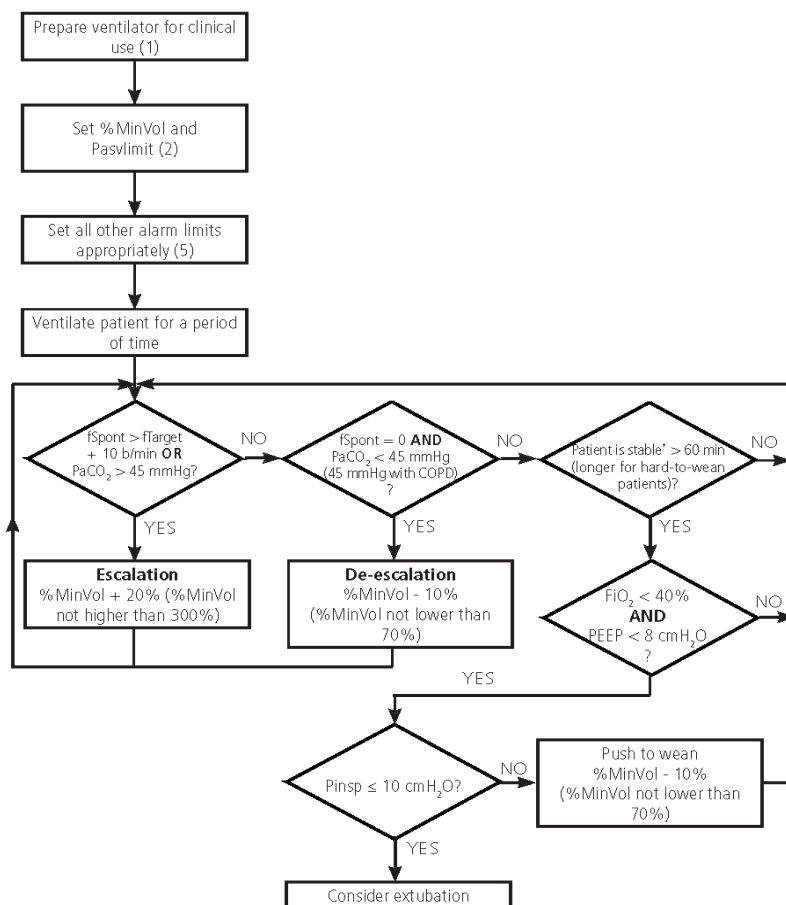
Maintain a **present minimum minute ventilation**,

- take spontaneous breathing into account,
- prevent tachypnea,
- prevent AutoPEEP,
- prevent excessive dead space ventilation,
- fully ventilate in apnea or low respiratory drive,
- give control to the patient if breathing activity is okay, and
- all this without exceeding a plateau pressure of 10 cmH₂O below the **upper pressure limit**.

This appendix explains in practical terms how to use ASV at the patient's bedside and provides a detailed functional description. Since Otis' equation (Otis 1950) is the cornerstone of the optimal-breath pattern calculation, this equation is included and described. A table of detailed technical specifications and pertinent references is also given.

C.2 ASV use in clinical practice

ASV does not require a special sequence of actions. It is used in much the same way as are conventional modes of ventilation. Figure C-1 summarizes how to use ASV, while the subsequent subsections explain it in detail. Figure C-2 shows the control settings active in the ASV mode.



* Stable means $f_{\text{Control}} = 0$ b/min AND $\text{PaCO}_2 \leq 45$ mmHg (50 mmHg with COPD)

Figure C-1. Clinical use of ASV. The numbers in parentheses are step numbers, which are explained in the next subsections.



Figure C-2. ASV basic controls

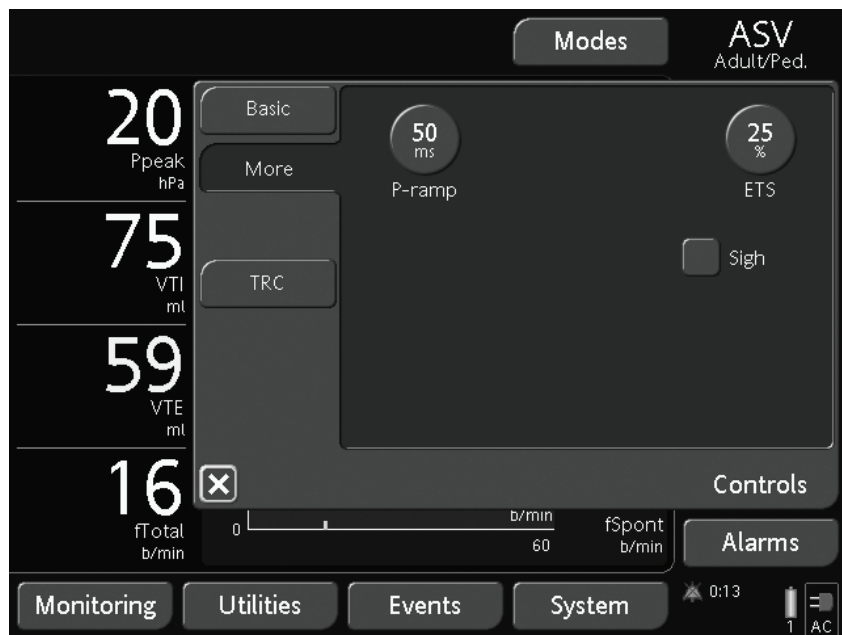


Figure C-3. ASV more controls

Step 1: Before connecting the patient to the HAMILTON-C2

It is important to prepare the HAMILTON-C2 for clinical use according to Section 2. This includes, but is not limited to, performing the preoperational procedures and testing indicated.

Step 2: Preparing the HAMILTON-C2 for ASV before ventilation

NOTE:

The high pressure limit must be at least 25 cmH₂O above PEEP/CPAP.

ASV requires that you set the following basic parameters:

Pressure	High Pressure alarm limit, in cmH ₂ O
Patient height	Patient height, in cm or in.
Gender	Sex of patient
%MinVol	Desired minute ventilation, in % of normal values

It is suggested you do the following before connecting the patient to the ventilator:

1. Remove the demonstration lung, when a demonstration lung is used, and silence the alarm.
2. Set the high Pressure alarm limit to an appropriate value (e.g., 45 cmH₂O or 50 cmH₂O for COPD patients). The maximum inspiratory pressure delivered in ASV (Pasv) will be **10 cmH₂O below the preset high pressure limit**, indicated by a blue band on the pressure curve display. The maximal inspiratory pressure for ASV can be also set using the Pasv control in the **Controls** window. Changing the Pasv value will also change high Pressure limit.
3. Activate ASV in the **Modes** window and then **Confirm** the mode change. The **Controls** window automatically opens.
4. Make the following control settings:
 - **Patient height**
 - **Gender**
 - **%MinVol.** A logical starting point is a %MinVol that will result in the same minute volume as a previous mode, if applicable. The %MinVol for a normal patient might be 100%; for a COPD patient, 90%; for an ARDS patient, 120%; and for other patients, 110%. Add 20% if body temperature > 38.5 °C (101.3 °F) and 5% per 500 m (1640 ft) above sea level.
 - **Trigger.** Suggested settings are a Flowtrigger of 2 l/min; or you can leave the previous patient trigger method and sensitivity, if applicable.

- **ETS.** A suggested setting is 25% (40% for a COPD patient); or you can leave this unchanged, if applicable.
- **TRC.** It is suggested that TRC be enabled, with Compensate set to 100%.
- **Other settings.** Set PEEP/CPAP and Oxygen values according to clinical requirements. You can leave the P-ramp setting at its standard value unless clinical judgment calls for adjustment. To set it, see Section 4.

5. **Confirm** the settings.

6. Connect the patient to the ventilator if applicable. This will initiate three test breaths.

Step 3: Compensation for changes in apparatus dead space

NOTE:

Changes in alveolar dead space due to ventilation/perfusion mismatch must be compensated via the %MinVol control.

The HAMILTON-C2 calculates the (anatomical or "series") dead space based on the IBW calculated from the patient height input. Dead space is calculated as 2.2 ml per kg (1 ml per lb). This dead space is a nominal value that is valid, on average, for intubated patients whose endotracheal tube is connected to the Y-piece of the ventilator by a standard catheter mount. If this dead space is altered by an artificial airway configuration such as the use of a heat and moisture exchange filter (HME) or nonstandard tubing, modify the Patient height setting accordingly to take into account the added or removed dead space.

Consider the following when compensating dead space:

- A shorter-than-standard endotracheal or tracheostomy tube probably does not require compensation.
- Different sizes of endotracheal tube probably do not require compensation.

-
- A much longer-than-normal catheter mount may require compensation.
 - A bacterial filter or an HME may require compensation. The volume of these devices, for an adult, is on average 50 to 60 ml, but may be as high as 95 ml (Mallinckrodt Hygroster). For an HME, a simple rule of thumb is to add 10% to the IBW (by adjusting the Patient height control).

Step 4: Adjusting ventilation: Maintaining adequate ventilation

WARNING

It is inappropriate to adjust the IBW (through the Patient height control) to change minute volume. Always use the %MinVol control to adjust minute volume.

Once ASV is started, the HAMILTON-C2 calculates an optimal breath pattern and associated target values for tidal volume and rate according to the rules in . ASV then adjusts the inspiratory pressure (P_{insp}) and machine rate (f_{Control}) to achieve the targets.

Once the calculated targets are reached, the result of the ventilation needs to be assessed. All HAMILTON-C2 monitored parameters can be used for this purpose. However, to assess respiratory acid-base status, it is recommended that arterial blood gases be measured and minute ventilation be adjusted accordingly. TableC-1 provides examples of how to adjust the %MinVol setting.

Table C-1. Blood gas and patient conditions and possible adjustments for ASV

Condition	%MinVol change	Remarks
Normal arterial blood gases	None	--
High PaCO ₂	Increase %MinVol	Pay attention to inspiratory pressures
Low PaCO ₂	Decrease %MinVol	Pay attention to mean pressures and oxygenation status
High respiratory drive	Consider increase in %MinVol	Consider sedation, analgesia, or other treatments
Low O ₂ saturation	None	Consider increase in PEEP/CPAP and/or Oxygen

Step 5: Alarm settings review and special ASV alarms

To monitor the breathing pattern, you must review the alarm settings periodically and set them according to clinically acceptable values. As described below, ASV changes the breathing pattern according to the respiratory system mechanics and within the boundaries resulting from the operator's settings for ASV. However, you can closely monitor ASV's actions through the alarm system, since the alarm settings work totally independently of ASV.

It is possible to select a %MinVol that is incompatible with the lung-protective rules that govern ASV (for a detailed description, see C 3-3). For example, the operator might want a high ventilation for a COPD patient in spite of severe pulmonary obstruction. In such a case, ASV tries to achieve the maximum possible ventilation and alarms that **ASV: Cannot meet target**. Such a case is shown in Figure C-4, where a high ventilation (300% at 70 kg) was set by the operator for a patient

with severely obstructed lungs ($R_{aw} = 40 \text{ cmH}_2\text{O}/(\text{l/s})$). The high ventilation moves the minimum minute volume curve to the right while the obstructive disease causes the safety limit of rate to shift to the left. These two effects cause the minute volume curve to lie outside the safety limits as determined by the lung-protective rules strategy (see functional description below). ASV thus chooses the safest point closest to the user-set minute volume.

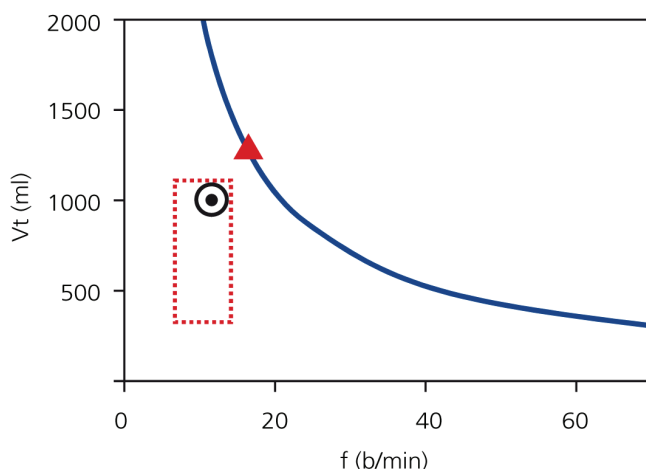


Figure C-4. Hypothetical example of high %MinVol setting incompatible with the lung-protective rules strategy. The open circle denotes the actual target, the closed triangle (never shown on the ventilator) denotes the (energetically) optimal target according to Otis' equation. The HAMILTON-C2 will alarm and inform the user that the ASV target cannot be achieved.

Step 6: Monitoring ASV

ASV interacts with the patient continuously. Whenever the patient's respiratory mechanics change, ASV adapts to this change. Whenever the patient's breathing activity changes, ASV adapts. To let you view the current status, the HAMILTON-C2 provides the ASV target graphics window (Figure C-5).

To monitor progress over time, it is recommended that you plot trends for P_{insp} , f_{Total} , and f_{Spont} . Interpret these trends, together with the %MinVol setting. TableC-2 through TableC-4 provide interpretation of typical ventilatory patterns. is a flow chart to guide you through the ASV adjustment/weaning process.

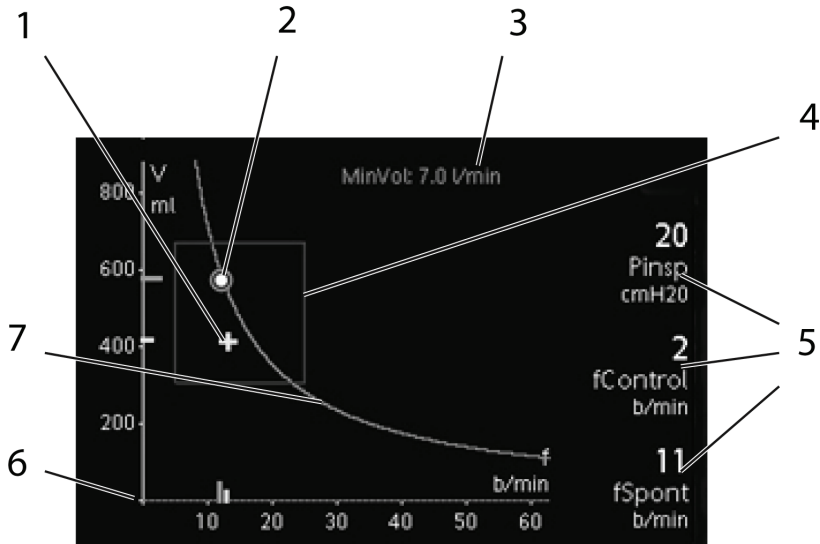


Figure C-5. ASV target graphics window

- 1 Current measured point, formed by intersection of measured tidal volume and rate.
- 2 Target point, formed by intersection of target tidal volume and target rate.
- 3 Numerical value of target minute volume
- 4 Safety frame in which target point may move.
- 5 f_{Spont} = spontaneous breath rate, $f_{Control}$ = machine rate, P_{insp} = inspiratory pressure set by ventilator.
- 6 Horizontal axis for rate (f). Vertical axis for tidal volume (Vt).
- 7 Minute volume curve.

Table C-2. Interpretation of breathing pattern at 100 % MinVol setting

Pinsp	fControl	fSpont	Interpretation
> 10	> 10	0	Fully controlled, mechanical ventilation. To start weaning, consider reducing %MinVol.
> 10	0	Acceptable	Supported spontaneous breathing. Consider reducing %MinVol.
< 8	0	Acceptable	Unsupported breathing. Consider extubation.
> 10	0	High	Dyspnea. Consider increasing %MinVol and other clinical treatments. Check for auto-triggering.

Table C-3. Interpretation of breathing pattern at much higher than 100% MinVol setting

Pinsp	fControl	fSpont	Interpretation
> 10	> 10	0	Fully controlled mechanical ventilation. Check arterial blood gases. To start weaning, consider reducing %MinVol.
> 10	0	Acceptable	Supported spontaneous breathing. Check reason for increased ventilation requirement. Consider reducing %MinVol.
< 8	0	Acceptable	Unsupported breathing. Check reason for increased ventilation requirement. Consider reducing %MinVol and extubation.
> 10	0	High	Dyspnea. Check reason for increased ventilation requirement. Consider other mode of ventilation and clinical treatment. Check for autotriggering.

Table C-4. Interpretation of breathing pattern at much lower than 100% MinVol setting

Pinsp	fControl	fSpont	Interpretation
>10	> 10	0	Danger of hypoventilation. Check arterial blood gases and consider increasing %MinVol.
>10	0	Acceptable	Enforced weaning pattern. Monitor arterial blood gases and patient respiratory effort. Consider decreasing or increasing %MinVol accordingly.
<8	0	Acceptable	Unsupported breathing. Consider extubation.
>10	0	High	Dyspnea. Consider increasing %MinVol and other clinical treatments. Check for auto-triggering.

Step 7: Weaning

Weaning patients from the ventilator is a clinical task that requires tremendous experience and involves more than just ventilation issues. This appendix does not intend to provide clinical information other than that needed to operate the ventilator with ASV.

ASV always allows patients to take spontaneous breaths. Episodes of spontaneous breathing can occur and are supported by ASV even within a period of fully controlled ventilation. In other words, weaning can start with ASV so early that it may go unrecognized clinically. It is therefore important to monitor the spontaneous efforts of the patient over time.

The weaning progress can be monitored in the trends display when inspiratory pressure (Pinsp), total rate (fTotal), and spontaneous rate (fSpont) are plotted. If the patient tolerates minimum respiratory support after a period of time with

$Pinsp < 8 \text{ cmH}_2\text{O}$ of Control = 0

weaning can be considered achieved, if minimum

fSpont is acceptable ExpMinVol is acceptable

What is "acceptable" must be defined by the clinician.

It may be necessary to reduce the %MinVol setting to 70% or even lower to "motivate" the patient to resume spontaneous breathing. If a patient can sustain minutes or even hours with a low %MinVol setting, it does not mean that weaning is complete. In fact, the %MinVol setting must always be interpreted in conjunction with the level of P_{insp} needed to achieve the set minute ventilation. Only if P_{insp} and f_{Control} are at their minimal values can weaning be assumed to be complete.

C.3 Detailed functional description of ASV

C.3.1 Normal minute ventilation

ASV defines normal minute ventilation according to the graph in Figure C-6.

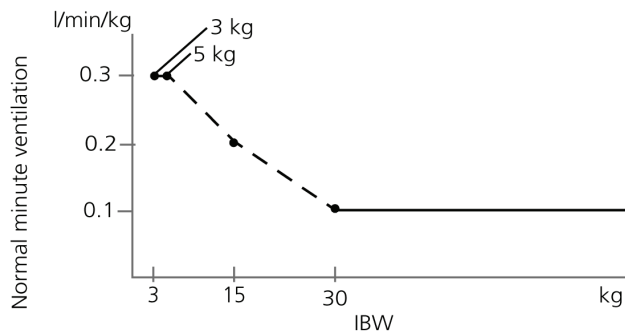


Figure C-6. Normal minute ventilation as a function of ideal body weight (IBW). For adult patients, minute ventilation is calculated as $0.1 \text{ l/kg} \times \text{IBW}$ (solid line). For pediatric patients, the value indicated by the dotted line is used. Minute ventilation for a 15 kg patient thus is calculated as $0.2 \text{ l/kg} \times 15 \text{ kg} = 3 \text{ l/min}$.

For example, for an IBW of 70 kg, normal minute ventilation corresponds to 7 l/min.

C.3.2 Targeted minute ventilation

When you chose ASV, you must select an appropriate minute ventilation for the patient. Minute ventilation is set with the %MinVol control, which, together with the Patient height control, determines the total minute ventilation in liters per minute.

A %MinVol setting of 100% corresponds to a normal minute ventilation, as discussed above. A setting less than 100% or higher than 100% corresponds to a minute ventilation lower or higher than normal.

From the %MinVol, the target minute ventilation (in l/min) is calculated as:

$$\text{Bodyweight (in kg)} \times \text{NormMinVent (in l/kg/min)} \times (\% \text{MinVol} / 100)$$

where NormMinVent is the normal minute ventilation from .

For example, with a %MinVol = 100 and an IBW = 70 kg, a target MinVol of 7 l/min is calculated. This target can be achieved with a number of combinations of tidal volume (Vt) and respiratory rate (f). This is shown in Figure C-7, where all possible combinations of Vt and f lie on the bold line, the target minute volume curve.

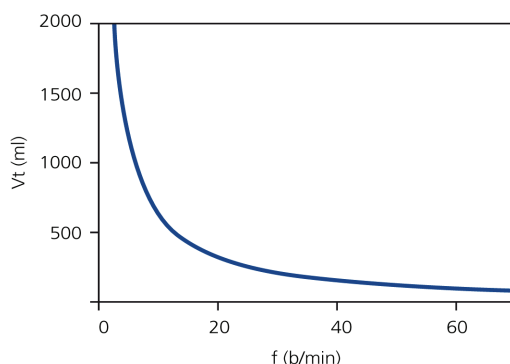


Figure C-7. MinVol = 7 l/min. All possible combinations of Vt and f which result in a minute ventilation of 7 l/min lie on the bold line.

C.3.3 Lung-protective rules strategy

Not all combinations of V_t and f shown in Figure C-7 are safe for the patient. The high tidal volumes will over distend the lungs and the small tidal volumes cannot produce alveolar ventilation at all. Another risk lies in inadequate respiratory rates. High rates can lead to dynamic hyperinflation or breath stacking, and thus inadvertent PEEP. Low rates can lead to hypoventilation and apnea. Therefore, it is necessary to limit the number of possible combinations of V_t and f . When limits are imposed on the possible combinations of V_t and f , then ASV uses a double strategy:

- The operator input for ASV determines the absolute boundaries.
- Internal calculations based on patient measurements further narrow the limits to counteract possible operator errors and to follow changes of respiratory system mechanics.

The effect of the strategy is shown in Figure C-8 and explained in the subsequent subsections.

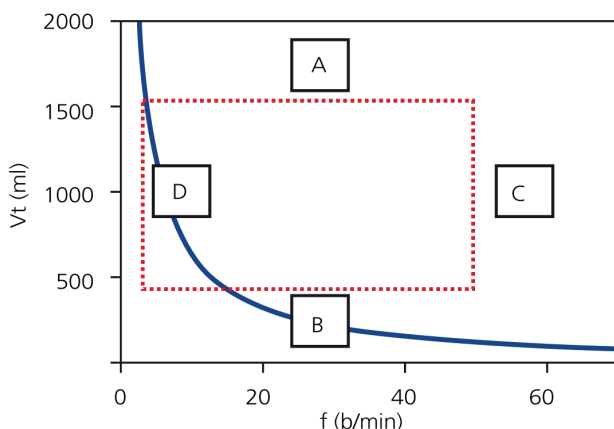


Figure C-8. Lung-protective rules strategy to avoid high tidal volumes and pressures (A), low alveolar ventilation (B), dynamic hyperinflation or breath stacking (C), and apnea (D)

A: High tidal volume limit

The tidal volume applied by ASV is limited (see A in Figure C-8) by two operator settings: high Pressure alarm limit, and Patient height.

The operator must set the high Pressure limit before connecting a patient to the ventilator. It was recommended by a group of physicians (Slutsky 1994) that the plateau pressure not exceed 35 cmH₂O. To achieve this with ASV, the high Pressure limit must be set to 45 cmH₂O. The maximum pressure to be applied in the ASV mode is 10 cmH₂O below the high Pressure limit.

For example, a normal 70 kg normal (post-operative) patient would have a compliance of about 50 ml/cmH₂O. A high Pressure limit of 45 cmH₂O will result in a maximum applied pressure of 35 cmH₂O. With a PEEP level of 5 cmH₂O, the effective pressure swing will be 30 cmH₂O. This in turn leads to an effective V_t of equal to, or less than 1500 ml. If the patient's lungs stiffen, to a compliance of 30 ml/cmH₂O, the maximum tidal volume becomes 900 ml.

If the operator sets the Pressure limit to a very high pressure, say 60 cmH₂O, the target volume is limited by the second criterion: 22 x IBW. For the 70 kg sample patient, a maximum target volume of 1540 ml results.

B: Low tidal volume limit

To determine the minimum target V_t in ASV (see B in Figure C-8) use the IBW calculated from the Patient height, which corresponds to 4.4 ml/kg. In this example for a 70 kg patient, the minimum target V_t is 308 ml.

The operator must use caution with low tidal volumes to avoid insufficient alveolar ventilation. The determining parameter for alveolar ventilation is dead space (V_{Daw}). Tidal volume value must always be greater than the V_{Daw} value. It is widely accepted that a first approximation of dead space can be obtained by the following simple equation (Radford 1954):

The lower limit for tidal volume is based on this equation and calculated to be at least twice the dead space. Or, the minimum V_t is $4.4 \times \text{IBW}$.

$$V_{\text{Daw}} = 2.2 \times \text{IBW} \quad (1)$$

C: High rate limit

You derive the maximum rate (see C in Figure C-8) from the operator-set %MinVol and the calculated IBW, which is calculated from the operator-set Patient height. The equation used to calculate the maximum rate is:

$$f_{\text{max}} = \text{target MinVol} / \text{minimum } V_t (2)$$

For example, the 70 kg patient described above will have a maximum rate of 22 b/min, when %MinVol is set to 100%.

However, as an example, if you choose an excessively high %MinVol of 350%, the maximum rate becomes 77 b/min. To protect the patient against such high rates, ASV employs a further safety mechanism, which takes into account the patient's ability to exhale.

A measure of the ability to exhale is the expiratory time constant (RCexp) (Marini 1989, Brunner 1995). To achieve a nearly complete exhalation to the equilibrium point of the respiratory system (90% of the maximum potential volume change), an expiratory time of at least $2 \times \text{RCexp}$ is theoretically required. For this reason, ASV calculates the maximum rate based on the principle of giving a minimum inspiratory time equal to $1 \times \text{RCexp}$ and a minimum expiratory time equal to $2 \times \text{RCexp}$, which results in these equations:

$$\begin{aligned} f_{\text{max}} &= 60 / (3 \times \text{RCexp}) = 20 / \text{RCexp} \\ f_{\text{max}} &\leq 60 \text{ b/min} (3) \end{aligned}$$

For example, the 70 kg patient with a respiratory system compliance of $50 \text{ ml/cmH}_2\text{O}$ (equal to $0.05 \text{ l/cmH}_2\text{O}$), an airway resistance including endotracheal tube of $5 \text{ cmH}_2\text{O/l/s}$, and a resistance of the expiratory hose and valve of another $5 \text{ cmH}_2\text{O/l/s}$, would have an RCexp of

$$0.05 \text{ l/cmH}_2\text{O} \times (5+5) \text{ cmH}_2\text{O/l/s} = 0.5 \text{ s}$$

and thus a maximum rate of 40 b/min. Since this value is higher than the one calculated above, the lower of the two values is in effect, that is, 22 b/min.

This limit applies to the respiratory rate of the ventilator only, *not* to the respiratory rate of the patient.

D. Low rate limit

The lowest target rate (see D in Figure C-8) is fixed at 5 b/min. This low rate in turn limits the maximum tidal volume to 1400 ml in the example of the 70 kg patient above, when %MinVol is set to 100%.

C.3.4 Optimal breath pattern

Although the lung-protective rules strategy limits possible combinations of V_t and f , ASV prescribes an explicit target combination. Using the example in Figure C-8, this shows considerable room for selection within the dotted rectangle. The selection process is an exclusive feature of ASV. The device works on the assumption the optimal breath pattern is identical to the one a totally unsupported patient will choose naturally (assuming the patient is capable of maintaining the pattern).

It is common knowledge that the choice of breathing pattern is governed by either work of breathing, or the force needed to maintain a pattern. ASV uses the original equation by Otis (Otis 1950) and calculates the optimal rate based on operator entries of %MinVol and the IBW (based on the Patient height setting) as well as on the measurement of RC_{exp} (see Section C-4).

For example, with the 70 kg patient, a setting of 100 %MinVol, and a measured RC_{exp} of 0.5 s, the optimal rate is 15 b/min according to Otis' equation.

Once the optimal rate is determined, the target V_t is calculated as:

$$V_t = \text{target MinVol} / \text{optimal rate(4)}$$

In the example of the 70 kg patient, the target V_t becomes 467 ml (see Section C-4 for details).

Figure C-9 shows the position of the target breathing pattern as well as the safety limits imposed by the lung-protective rules strategy.

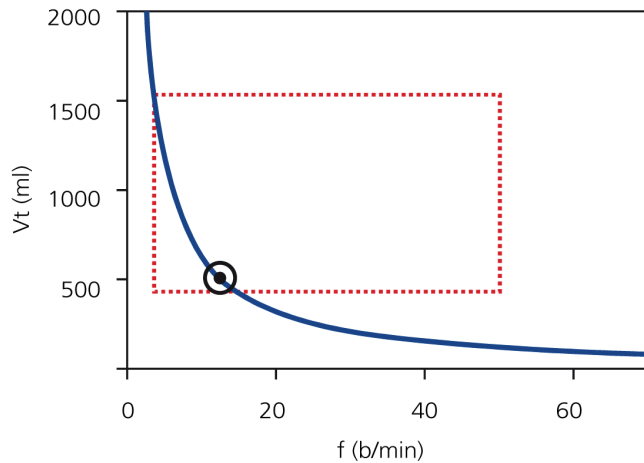


Figure C-9. Anatomy of the ASV target graphics window.
The rectangle shows the safety limits; the circle shows the target breath pattern.

C.3.4.1 Initial breaths: How ASV starts

How does the operator make this determination: how to achieve the target values in a given patient if it is not known whether or not the patient can breathe spontaneously? For this purpose, ASV uses a synchronized intermittent mandatory pressure ventilation mode.

Each breath triggered by the patient is pressure-supported and flow-cycled, or, the transition to exhalation is made based on flow. In contrast, if the patient does not trigger the breath, the delivery of the breath is pressure-preset and time-cycled.

The operator-set controls (manual):

- PEEP/CPAP
- Oxygen
- P-ramp
- ETS
- Trigger type and sensitivity

This list of controls is adjusted automatically by ASV, and cannot be adjusted by the operator:

- SIMV rate: to change total respiratory rate
- Inspiratory pressure level: to change inspiratory volume
- Inspiratory time: to allow gas flow into the lungs
- Startup breath pattern

To safely start ASV, the operator inputs the Patient height setting, which is used to calculate the IBW.

Three initial test breaths are delivered. The resulting rate and tidal volume are measured and compared with the target values. ASV then responds to the differences between the actual and target Vt as well as the actual and target rates.

C.3.4.2 Approaching the target

Figure C-10 shows a possible scenario after the three initial test breaths. The actual breath pattern, which is plotted as the patient symbol, shows clear deviation from the target. The task of ASV is now to move the patient symbol as close to the circle as possible.

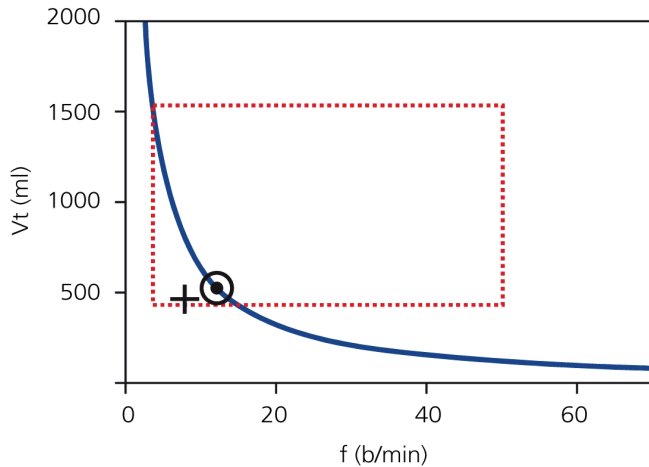


Figure C-10. Example of a situation after the three initial breaths. The patient symbol marks the actual measured values for V_t and rate.

To achieve the target, use this strategy:

- If actual $V_t <$ target V_t , the inspiratory pressure is increased.
- If actual $V_t >$ target V_t , the inspiratory pressure is decreased.
- If actual $V_t =$ target V_t , the inspiratory pressure is left unchanged.
- If actual rate $<$ target rate, the SIMV rate is increased.
- If actual rate $>$ target rate, the SIMV rate is decreased.
- If actual rate $=$ target rate, the SIMV rate is left unchanged.

As a result, the patient symbol in Figure C-10 moves toward the circle. The actual V_t is calculated as the average of inspiratory and expiratory volumes of the last 5 breaths. This definition compensates in parts for leaks in the breathing circuit, including the endotracheal tube.

C.3.5 Dynamic adjustment of lung protection

The operator preset values are not changed by ASV, and the corresponding safety limits remain as defined above. However, if the respiratory system mechanics change, the safety limits change accordingly and as defined in Section C.3-3. The safety limits are updated on a breath-by-breath basis.

For example, if the lungs stiffen, the high V_t limit is lowered proportionally, and the high Rate limit is increased according to Equation 5.

This dynamic adjustment ensures that ASV applies a safe breathing pattern at all times. In graphical terms, the dotted rectangle changes as shown in Figure C-11.

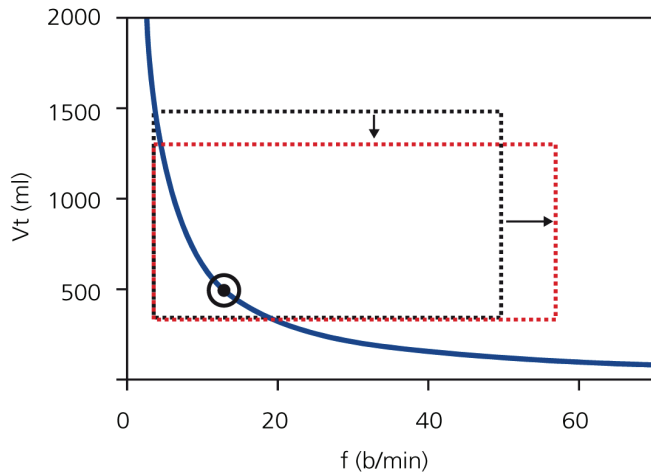


Figure C-11. Lung-protective limits are changed dynamically and according to the respiratory system mechanics. However, the limits derived from the operator input are never violated.

C.3.6 Dynamic adjustment of optimal breath pattern

After calculated, the optimal breath pattern is revised with each breath according to the measurements of RC_{exp} . Apply Otis' equation and a new target breathing pattern is calculated. The targets do not change under steady-state conditions. However, if the patient's respiratory system mechanics change, the target values also change.

In this example: the bronchi of our normal 70 kg sample patient (being ventilated at 15 b/min and with a V_t of 467 ml) constrict due to asthma, and the expiratory resistance increases to values higher than 5 cmH₂O/l/s. For this reason, more time is needed during exhalation for the lungs to reach the end-expiratory equilibrium position. In technical terms, the RC_{exp} has increased and this increase requires a longer expiratory time.

For a given minute ventilation, this calls for an increase in V_t and a decrease in rate (longer expiratory time). Otis' equation yields new targets:

$f = 11$ b/min and $V_t = 636$ ml.

Figure C-12 shows the change. Notice also that the increase in resistance results in a decrease in the volume/pressure ratio (V/P). The changes in RC_{exp} and dynamic compliance affect the safety limits accordingly and with each breath (see previous subsection).

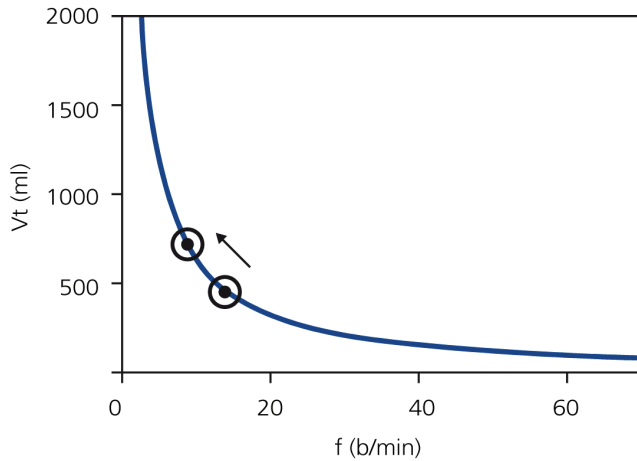


Figure C-12. Changes of target values in broncho-constriction. For clarity, the safety limits are omitted. For clinical examples, see Belliato 2000.

C.4 Minimum work of breathing (Otis' equation)

Otis' basic question was: how do mammals choose their breathing pattern and on what parameters does it depend (Otis 1950)? The same question was investigated years before by Rohrer and a very similar result was obtained (Rohrer 1925). The hypothesis was that the breath pattern with the least work of breathing (WOB) is chosen by mammals. Figure C-13 shows the relationship between rate and WOB graphically, for resistive load, elastic load, and total load to breathing.

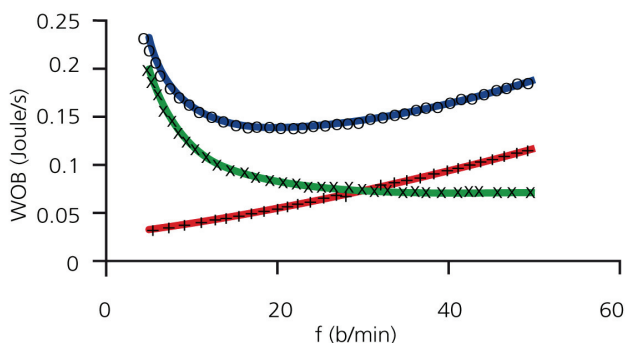


Figure C-13. Three different relationships between rate and WOB are plotted for a hypothetical lung: (+) purely resistive load causes WOB to rise with rate, (x) purely elastic load creates highest load at low rates, (o) the total lung shows a clear minimum which can be calculated according to the equation below.

The following equation was found to represent the rate where WOB is minimum:

$$f = (1 + 2a \cdot RCe \cdot (\text{MinVol} - f \cdot Vd) / (Vd))^{-0.5} - 1/a \cdot RCe$$

where a is a factor that depends on the flow waveform. For sinusoidal flows, a is $2\pi^2/60$.

The corresponding tidal volume is calculated as:

$$Vt = \text{MinVol}/f$$

Example: A 70 kg male patient with normal lungs ($R_{\text{total}} = 5 \text{ cmH}_2\text{O/l/s}$, expiratory resistance hose and valve = $5 \text{ cmH}_2\text{O/l/s}$, $C_{rs} = 50 \text{ ml/cmH}_2\text{O}$) may have a measured RC_{exp} of 0.5 s, an estimated VD_{aw} of 154 ml, and an operator-set %MinVol of 100%. With these values, the target MinVol becomes

$$\text{MinVol} = 100\% \times 70 \text{ kg} \times 0.1 \text{ l/min/kg} = 7 \text{ l/min}$$

Next, Otis' equation is applied with the following parameters:

$$\text{MinVol} = 7 \text{ l/min}$$

$$VD_{aw} = 154 \text{ ml}$$

$$RC_{exp} = 0.5s$$

$$a = 2\pi^2/60$$

$$f = 10 \text{ b/min (this is always used as a starting value)}$$

The result is a new rate $f(1)$

$$f(1) = 15 \text{ b/min}$$

This rate is again inserted into Otis' equation, the calculation is performed again, and the next estimate for rate $f(2)$ is obtained. This procedure is repeated until the difference between subsequent results for rate (f) becomes lower than 0.5 b/min. In the present example, one iteration step is sufficient, i.e.,

$$f_{target} = 15 \text{ b/min}$$

Finally, the target tidal volume is obtained by dividing MinVol by f :

$$V_{target} = 7000 \text{ ml/min} / 15 \text{ b/min} = 467 \text{ ml}$$

C.5 ASV technical data

Table C-5 lists technical data related to ASV. *Underlined> parameters are operator-set in the ASV mode.*

Table C-5. ASV technical data

ASV-related operator settings	
%MinVol	25 to 350%
Patient height	130 to 250 cm / 50 to 100 in. (adult) 30 to 150 cm / 12 to 60 in. (pediatric)
Internal calculations	
IBW	In kg, calculated based on Patient height and Gender (see Section 4.2)

Table C-5. ASV technical data

MinVol (target)	In l/min, target minute volume is calculated as: $\text{IBW (in kg)} \times \text{NormMinVent (in l/kg/min)} \times \% \text{MinVol}/100$ where NormMinVent is the normal minute ventilation from Figure D-6.
fTotal	In b/min, calculated on the basis of Otis' equation
VDaw	2.2 ml/kg IBW
Vt (target)	MinVol/ f(target)
ASV monitor	
Target values (numerical)	MinVol, Vt, fTotal
Current achieved values (numerical)	MinVol, Vt, fTotal
Status of patient (numerical)	fSpont, fControl, Pinsp
Graphics display (curve)	f versus Vt, target value, actual value, safety boundaries
Alarms	
All alarms are functional except apnea alarms	See Section 8
Special	ASV: Check hi press limit, ASV: Cannot meet target
Performance specifications	
Response time (90% of steady state)	< 1 min (typical)
Overshoot/undershoot	< 20%
Maximum pressure change per breath	2 cmH ₂ O

Table C-5. ASV technical data

Lung-protective rules	
Maximum Vt	Depends on high <i>Pressure</i> alarm limit and volume/pressure ratio (V/P) always < 22 x IBW
Minimum Vt	4.4 x IBW
Maximum machine rate	Depends on R _{Xexp} , but always < 23 b/min * %MinVol/100 (adults and but always < 60 b/min
Minimum target rate	5 to 15 b/min
Maximum P _{insp}	High <i>Pressure</i> alarm limit - 10 cmH ₂ O - PEEP
Minimum P _{insp}	5 cmH ₂ O above <i>PEEP/CPAP</i>
Minimum inspiratory time (T _I)	0.5 s or R _{Cexp} , whichever is longer
Maximum inspiratory time (T _I)	2 s
Minimum expiratory time (T _e)	2 x R _{Cexp}
Maximum expiratory time (T _e)	12 s
I:E range	1:4 to 1:1

C.6 ASV Start up

When ASV is started, the device delivers 3 (three) test breaths in the synchronized intermittent mandatory pressure ventilation mode. The device automatically selects the values for SIMV rate, inspiratory time (TI), and inspiratory pressure (P_{insp}) based on the calculated IBW, which is determined from the operator-set Patient height and Gender settings, and according to information described in Table C-6 and Table C-7.

Table C-6. Initial breath pattern for Adult settings

IBW (kg)	P _{insp} (cmH ₂ O)	TI (s)	SIMV rate (b/min)	Minimum target rate (b/min)
30 to 39	15	1	14	7
40 to 59	15	1	12	6
60 to 89	15	1	10	5
90 to 99	18	1.5	10	5
> 100	20	1.5	10	5

Table C-7. Initial breath pattern for Pediatric settings

IBW (kg)	P _{insp} (cmH ₂ O)	TI (s)	SIMV rate (b/min)	Minimum target rate (b/min)
3 to 5	15	0.4	30	15
6 to 8	15	0.6	25	12
9 to 11	15	0.6	20	10
12 to 14	15	0.7	20	10
15 to 20	15	0.8	20	10

Table C-7. Initial breath pattern for Pediatric settings

IBW (kg)	P insp (cmH ₂ O)	TI (s)	SIMV rate (b/min)	Minimum target rate (b/min)
21 to 23	15	0.9	15	7
24 to 29	15	1	15	7

C.7 References

- **Hewlett AM, Platt AS, Terry VG.** Mandatory minute volume. A new concept in weaning from mechanical ventilation. *Anaesthesia* 1977, 32:163-9.
- **Radford EP jr.** Ventilation standards for use in artificial respiration. *N Engl J Med* 1954, 251:877-83.
- **Otis AB, Fenn AWO, Rahn H.** Mechanics of breathing in man. *J Appl Physiol* 1950, 2:592-607.
- **Marini JJ, Crooke PS, Truwit JD.** Determinants and limits of pressure-preset ventilation: a mathematical model of pressure control. *J Appl Physiol* 1989, 67:1081-92.
- **Slutsky AS.** Consensus conference on mechanical ventilation- January 28-30, 1993 at Northbrook, Illinois, USA. *Int Care Med* 1994, 20:64-79.
- **Lourens MS, Van den Berg BV, Aerts JGJ, Verbraak AFM, Hoogsteden HC, Bogtaard JM.** Expiratory time constants in mechanically ventilated patients with and without COPD. *Int Care Med* 2000, 26:1612-18.
- **Quan SF, Parides GC, Knoper ST.** Mandatory Minute Volume (MMV) Ventilation: An Overview. *Resp Care* 1990, 35:898-905.
- **Belliato M, Maggio M, Neri S, Via G, Fusilli N, Olivei M, Lotti G, Braschi A.** Evaluation of the adaptive support ventilation (ASV) mode in paralyzed patients. *Intensive Care Med* 2000, 26, Suppl. 3:S327.
- **...more** and updated references on www.hamilton-medical.com

D NIV (non invasive ventilation)

D.1	Introduction	D-2
D.2	Benefits of noninvasive ventilation,	D-3
D.3	Required conditions for use	D-4
D.4	Contraindications	D-4
D.5	Potential adverse reactions	D-5
D.6	Selecting a patient interface	D-5
D.7	Control settings	D-6
D.8	Alarms	D-7
D.9	Monitored parameters	D-8
D.10	Additional notes about using noninvasive ventilation	D-9
D.11	References	D-11

D.1 Introduction

NOTE:

- Noninvasive ventilation in critically ill patients should only be used by properly trained and experienced personnel.
 - As a precaution, you must be prepared to intubate the patient and start invasive ventilation at any time while noninvasive ventilation is in use.
 - The use of a mask can increase dead space. Always comply with the mask manufacturer's instructions when using noninvasive ventilation.
-

The noninvasive ventilation mode (NIV) and the spontaneous/timed noninvasive ventilation mode (NIV-ST) are implementations of noninvasive positive pressure ventilation (NPPV). NPPV can use as its patient interface a mask, mouthpiece, or helmet-type interface, rather than an invasive conduit such as an endotracheal tube.

Used for years in home care and subacute care settings, NPPV can also benefit intensive care ventilation patients by decreasing the need for intubation and promoting early extubation. Benefits such as reduced mortality (COPD patients), reduced ventilation time (COPD and ARF patients), and reduced complication rates (of ventilator-associated pneumonias) have been clearly demonstrated^{1,2}.

1. Mehta S et al. Noninvasive ventilation. *Am J Respir Crit Care Med* 2001 Feb;163(2):540-77.

2. Hess DR. The evidence for noninvasive positive-pressure ventilation in the care of patients in acute respiratory failure: a systematic review of the literature. *Respiratory Care* 2004 Jul;49(7):810-25.

Intended for actively breathing patients, noninvasive ventilation is provided through a nonvented or nonported mask interface. Because this open breathing circuit permits air to leak around the mask or through the mouth, the ventilator achieves and maintains the prescribed pressure by adjusting the inspiratory flow. If the leak is large, the ventilator's inspiratory flow can be large -- up to 240 l/min -- thus compensating at least in part for most leaks. The NIV modes were also designed to minimize nuisance leak-related alarms.

NIV is an adaptation of the SPONT mode, while NIV-ST is an adaptation of the PSIMV+ mode. The primary difference between SPONT and NIV or PSIMV+ and NIV-ST is that SPONT and PSIMV+ are designed for an intubated patient, while the NIV modes are designed for use with a mask or other noninvasive patient interface. See Appendix A for technical details about the ventilator's noninvasive modes.

D.2 Benefits of noninvasive ventilation^{1,2}

Noninvasive ventilation offers these short-term benefits:

- Relieves respiratory symptoms
- Optimizes patient comfort
- Reduces work of breathing
- Improves or stabilizes gas exchange
- Improves patient-ventilator synchrony
- Minimizes risks associated with aspiration, intubation, injury to the mucus membranes and teeth, and circulatory reactions

Noninvasive ventilation offers these long-term benefits:

- Improves sleep duration and quality
- Maximizes quality of life

-
1. Mehta S et al. Noninvasive ventilation. *Am J Respir Crit Care Med* 2001 Feb;163(2):540-77.
 2. Hess DR. The evidence for noninvasive positive-pressure ventilation in the care of patients in acute respiratory failure: a systematic review of the literature. *Respiratory Care* 2004 Jul;49(7):810-25.

- Enhances functional status
- Prolongs survival

D.3 Required conditions for use

CAUTION

- **To prevent possible patient injury, DO NOT use noninvasive ventilation on patients with no or irregular spontaneous breaths. Noninvasive ventilation was intended to provide supplemental ventilatory support to patients with regular spontaneous breaths.**
 - **To prevent possible patient injury, DO NOT attempt to use noninvasive ventilation on intubated patients.**
-

Ensure these requirements are met to use noninvasive ventilation:

- The clinician's instructions must be strictly followed.
- The patient must not be intubated.
- The patient must be able to trigger the ventilator and must have regular spontaneous breaths.
- The patient must be conscious.
- The patient must be able to maintain an adequate airway.
- The patient must be monitored by external monitors.
- Intubation must be possible at any time.
- The mask should fit face structures well.

D.4 Contraindications

- Intolerance of interface
- Inability to trigger breath
- Facial or brain injury
- Recent upper airway or esophageal surgery

- Hemodynamic instability
- Gastric distension
- Inability to protect airway

D.5 Potential adverse reactions

- Skin breakdown from interface (pressures sores)
- Aspiration
- Conjunctivitis
- Gastric insufflation
- Claustrophobic reaction
- Potential hemodynamic instability

D.6 Selecting a patient interface

The quality and performance of the patient interface largely determine the effectiveness of noninvasive ventilation. Either a face (oronasal) mask which covers the mouth and nose, a nasal mask which covers the nose only, a mouthpiece, or a helmet-type interface can be used with noninvasive ventilation. In general, a face mask is more efficient than a nasal mask, but a nasal mask is better tolerated. Consider these additional advantages and disadvantages when selecting a patient interface shown in Table D-1.

Type	Advantage	Disadvantage
Face mask	• Little patient cooperation required • Little leakage • Ability to sleep	• Verbal communication not possible • Gastric distension • Greater dead space

Type	Advantage	Disadvantage
Nasal mask	• Comfort • Verbal communication possible • Little dead space	• Patient cooperation required • Oral leakage
Mouthpiece	• Simple to use • Inexpensive	• Nasal air leakage • Greater dead space

In general, a mask used with the noninvasive modes can meet these requirements:

- It must be of the non-vented/non-ported design
- Gas leakage should be controllable at low mask application pressures
- The material in contact with the face should be soft, bio-compatible, and nonallergenic
- It should be easy to install and remove
- It should remain properly positioned when the patient moves their head

If you try using a nasal mask, but there is significant gas leakage through the open mouth, switch to a face mask.

D.7 Control settings

CAUTION

- **When ventilating with a mask, avoid high airway pressures. High pressures may cause gastric distension.**
- **Peak pressures exceeding 33 cmH₂O may increase the risk of aspiration due to gastric insufflation¹. When ventilating with such pressures, consider using an invasive mode.**

When a significant leak occurs, the inspiratory flow can never fall below ETS, thus not allowing the ventilator to cycle into exhalation and resulting in endless inspiration. For this reason, the TI max setting was added, providing an alternative way to cycle into exhalation. When inspiration lasts longer than TI max, the ventilator cycles into exhalation.

When the ventilator cycles are based on ETS setting rather than TImax, it is the most comfortable for the patient. Ensure the TI max setting is sufficiently long to give ETS the chance to cycle the ventilator. Adjusting the TI max setting increases or decreases the allowable inspiratory time. Increasing ETS above the default 25% allows the ventilator to cycle to terminate inspiration at a higher flow, to accommodate larger leaks.

Other controls require special attention. Carefully observe the patient/ventilator interaction. The leakage in this mode reduces the actual applied PEEP/CPAP and give rise to autotriggering. Adjust Psupport or PInsp to obtain appropriate tidal volumes. Adjust PEEP/CPAP further, considering oxygenation and AutoPEEP.

D.8 Alarms

Volume alarms are less meaningful in noninvasive than in other modes, because of the unpredictable gas leakage in these modes. Alarms are based on the returned expiratory gas volume measured at the Flow Sensor; this value can be significantly lower than the delivered tidal volume, because the delivered tidal volume is the sum of the displayed VTE and the leakage volume. To avoid nuisance volume alarms, set the low Vt and ExpMinVol alarms to a low level.

Because the noninvasive modes are pressure modes, however, do pay attention to the pressure-related alarms. If the defined PEEP and inspiratory pressure can be maintained, the ventilator is compensating the gas leak sufficiently.

-
1. Bach JR, Alba AS, Saporito LR. Intermittent positive pressure ventilation via the mouth as an alternative to tracheostomy for 257 ventilator users. *Chest* 1993;103:174-182.

D.9 Monitored parameters

NOTE:

Due to the changing and unpredictable amount of leakage, these numeric monitoring parameters cannot be used for reliable analysis of patient conditions: RCexp, Rinsp, Insp Flow, AutoPEEP, and Cstat. Continuous monitoring of the clinical parameters and patient comfort is of critical importance. The parameters VTE NIV, ExpMin-NIV, MVSpont NIV and MVLeak are leak compensated. These parameters are estimations and may not reflect exact values.

Due to the leakage at the patient interface, displayed exhaled volumes in the noninvasive modes can be substantially smaller than the delivered volumes. The Flow Sensor (a bidirectional device proximal to the patient) measures the delivered volume and the exhaled tidal volume. In order to estimate the exhaled tidal volume, the expiratory minute volume, the spontaneous expiratory minute volume and the minute volume lost over the leakage the monitoring parameters VTE, ExpMinVol, MVSpont and Leak are exchanged with VTE NIV, ExpMinVol NIV, MVSpont NIV and MVLeak. These NIV parameters take into account the measured leak during non-invasive ventilation.

While a leak at the patient interface influences the tidal volume measurement, leaks in the breathing circuit itself do not influence the tidal volume measurement.

Besides all the other clinical parameters, TI, Ppeak, PEEP/CPAP, I:E, fTotal, Pmean, and fSpont can be used to assess the patient's ventilatory status as usual.

D.10 Additional notes about using noninvasive ventilation

NOTE:

If the mask fit cannot be improved, select an alternative treatment method.

Due to some unique characteristics of noninvasive ventilation, consider the following points when using it. Consistent with best practices, monitor the patient closely to evaluate the adequacy of the prescribed therapy.

IntelliTrig (intelligent trigger) function. With its IntelliTrig function, the ventilator can automatically adapt to changing breath patterns and system leaks to achieve optimum synchronization between patient and device.

To synchronize, IntelliTrig compensates any leaks and resistances between the ventilator and the patient, and with each breath it measures the leakage at the patient interface (mask). With this information IntelliTrig adapts the trigger mechanism so leakage and the changing breath pattern do not influence the operator-set trigger sensitivity (flow trigger).

Maintaining PEEP and preventing autotriggering. Significant leakage can be present in noninvasive ventilation, which can serve to reduce the actual applied PEEP/CPAP and give rise to autotriggering. If you cannot reach the set PEEP/CPAP, check the mask fit.

The ventilator maintains PEEP with the expiratory valve in combination with a compensating base flow delivered by the inspiratory valve through the breathing circuit.

The **Loss of PEEP** alarm alerts you to uncompensated leaks (that is, when the measured PEEP/CPAP is 3 cmH₂O lower than the set PEEP/CPAP).

Inspect mask fit and position. For noninvasive ventilation to function as intended, the mask must fit well and remain in place. It is desirable to maintain a good seal and minimize leakage.

Inspect the mask position regularly and adjust as necessary. If the mask slides away from the mouth and nose (patient disconnection), reinstall and secure it. React promptly and appropriately to any alarms.

The ventilator's Leak parameter provides one indicator of mask fit. To check the proper fit of the mask verify that the patient can trigger and flow-cycle inspiration and by verify that:

$$P_{\text{peak}} = (PEEP/CPAP + P_{\text{support}}/P_{\text{insp}}) \pm 3 \text{ cmH}_2\text{O}.$$

CO2 rebreathing in noninvasive ventilation.

CO2 rebreathing per breath can increase in noninvasive ventilation. Typically this is not critical, because there is also generally significant leakage in noninvasive ventilation. CO2 rebreathing can occur, because there is not the usual dead space reduction from an endotracheal tube or tracheostomy. And because the mask or other noninvasive interface creates additional dead space. Consider this additional dead space when prescribing a specific type of noninvasive patient interface. Despite the use of a noninvasive interface, the dead space ventilation per minute can decrease when the therapy results in an increase in tidal volume and decrease in respiratory rate.

D.11 References

- **Hess DR.** The evidence for noninvasive positive-pressure ventilation in the care of patients in acute respiratory failure: a systematic review of the literature. *Respir Care* 2004 Jul;49(7):810-25.
- **Mehta S et al.** Noninvasive ventilation. *Am J Respir Crit Care Med* 2001 Feb;163(2):540-77.
- **Arroliga AC.** Noninvasive positive pressure ventilation in acute respiratory failure: does it improve outcome? *Cleveland Clin J Med.* 2001 Aug;68(8):677-80.
- **Hill NS.** Noninvasive ventilation in chronic obstructive pulmonary disease. *Clin Chest Med.* 2000 Dec;21(4):783-97.
- **AARC.** Consensus statement: Noninvasive positive pressure ventilation. *Respir Care* 1997;42(4):365-9.
- **Evans TW et al.** Noninvasive positive pressure ventilation in acute respiratory failure: Report of an international consensus conference in intensive care medicine, Paris, France, 13 - 14 April 2000. *Resuscitation* 2001;10:112-25.

APPENDIX **E** CO₂ sensor option: Volumetric capnography

E.1	Introduction	E-2
E.2	CO ₂ elimination ($V'\text{CO}_2$)	E-3
E.3	End-tidal CO ₂ (PetCO ₂ and FetCO ₂)	E-5
E.4	Airway dead space (V _{Daw})	E-5
E.5	Alveolar minute ventilation ($V'\text{alv}$)	E-6
E.6	Capnogram shape (slope of the alveolar plateau, slopeCO ₂)	E-7
E.7	Formulas	E-9
E.8	References	E-10

E.1 Introduction

NOTE:

The Airway dead space (V_{Daw}) is in approximation to the anatomical dead space.

Capnography has become an important tool to evaluate the adequacy of ventilation, as the obvious goal of ventilation is to remove the CO₂ produced by the body's metabolic processes. But conventional, time-based capnography allows only qualitative and semi-quantitative, and sometimes misleading, measurements, so volumetric capnography has emerged as the preferred method to assess the quality and quantity of ventilation.

To this end, the volumetric capnography measurements provide the following information:

- The CO₂ elimination ($V'\text{CO}_2$) measurement permits assessment of metabolic rate (e.g., it is high with sepsis, tetanus, etc.) and treatment progress.
- The end-tidal CO₂ ($P_{et}\text{CO}_2$ and $F_{et}\text{CO}_2$) measurements permit assessment of arterial CO₂ (Note that they are inaccurate in pulmonary embolism.).
- The airway dead space (V_{Daw}) and alveolar minute ventilation (V'_{alv}) measurements permit assessment of actual alveolar ventilation (as opposed to minute ventilation).
- The capnogram shape (slopeCO_2) permits assessment of COPD, asthma, and inefficient ventilation.
- The physiological dead space fraction (V_D/V_t) permits assessment of risk (Nuckton 2002).

E.2 CO₂ elimination ($V'\text{CO}_2$)

To convert a time-based capnogram into a volumetric capnogram, CO₂ must be combined with flow. Figure E-3 shows the volume of CO₂ exhaled in one breath, combining a typical FetCO_2 versus time curve (Figure E-1) with the flow curve (Figure E-2) for a mechanically ventilated patient. The area under the expiratory curve (B) minus the area under the inspiratory curve (A) is the net transfer of CO₂ out of the lungs per breath, or $V\text{CO}_2$.

CO₂ elimination ($V'\text{CO}_2$) is obtained by adding $V\text{CO}_2$ over several breaths and dividing the sum by the total time in minutes (Noe 1963). Steady-state conditions are essential to interpret the $V'\text{CO}_2$ values (Brandi 1999). $V'\text{CO}_2$ thus represents CO₂ elimination but not necessarily CO₂ production. Normal values for $V'\text{CO}_2$ can be found in the literature or in Table E-1.

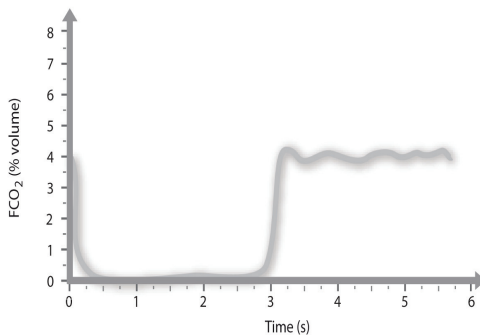


Figure E-1. Typical capnogram of patient on pressure-controlled ventilation, showing fractional concentration of CO₂ plotted against time.¹

1. Inspiration starts at time 0; exhalation, at approximately 2.75 s. Note that inspiratory gas initially contains CO₂ (rebreathing) that is washed out of the Y-piece.

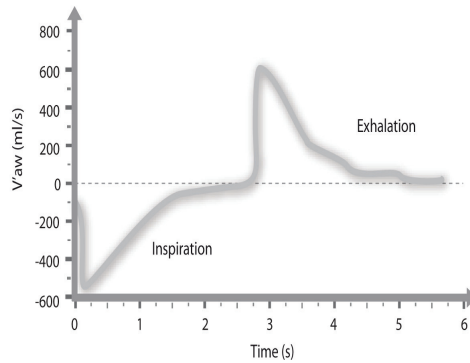


Figure E-2. Typical spirogram of a patient on pressure-controlled ventilation (same breath as shown in Figure E-1).¹

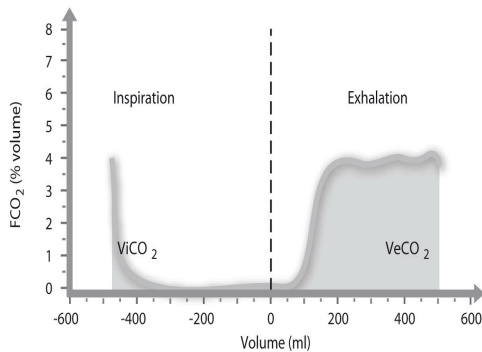


Figure E-3. Combination of capnogram and spirogram (that is, fractional end-tidal CO₂ concentration plotted against volume).²

1. The flow into the patient (inspiration) is negative, while the flow out of the patient (exhalation) is positive. The expiratory flow curve is an exponential decay curve. Note that in spontaneously breathing subjects, the flow curves may be of different shapes.

E.3 End-tidal CO₂ (PetCO₂ and FetCO₂)

The maximum value of CO₂ measured during exhalation is normally considered the end-tidal CO₂ value, and is either given as a partial pressure (PetCO₂) or as a fractional concentration of CO₂ in dry gas (FetCO₂).

Normal values for PetCO₂ and FetCO₂ can be found in the literature or in Table E-1.

E.4 Airway dead space (VDaw)

Airway dead space measurement using a volumetric capnogram gives an effective, in-vivo measure of volume lost in the conducting airways. By dividing the capnogram into phases¹ (Figure E-4), VDaw can be calculated as the smallest measurable dead space, essentially the volume exhaled up until phase II. The calculation, described in detail elsewhere (Wolff 1989 and Aström 2000), consists of a number of computational steps, which take the slope of the alveolar plateau into account.

Normal values for VDaw can be found in the literature or in Table E-1.

2. ViCO₂ is the volume of inspired CO₂, while VeCO₂ is the volume of exhaled CO₂. The net elimination of CO₂ is VeCO₂ - ViCO₂. ViCO₂, which is a negative volume indicating rebreathed CO₂, is normally omitted.

1. In an early detailed description (Folkow 1955), the capnogram can be thought of as being divided into phases: phase I (no CO₂ present), phase II (rapid rise in CO₂), and phase III (alveolar plateau).

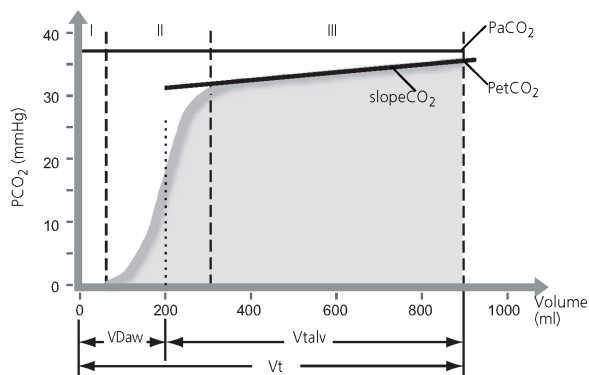


Figure E-4. Interpretation of volumetric capnogram.¹

E.5 Alveolar minute ventilation (V'_{alv})

Minute ventilation includes not only ventilation of the lungs, but also ventilation that is wasted in the airways. Thus, high minute ventilation does not conclusively indicate the actual alveolar reach. For example, a tidal volume of 100 ml at 80 b/min yields the same minute ventilation as a tidal volume of 500 ml at 16 b/min, yet it has no real benefit to the patient since only dead space ventilation occurs. Alveolar ventilation is defined as

$$V'_{\text{alv}} = \text{MinVol} - V'D_{\text{aw}}$$

where

$$\text{MinVol} = f \cdot V_t$$

and

$$V'D_{\text{aw}} = f \cdot V_{D_{\text{aw}}}$$

or

1. Phase I: pure airway dead space, from point of measurement of CO₂ toward the lungs. Phase II: weighted average of alveolar gas from different lung spaces, at the sensor location; measurement is $V_{D_{\text{aw}}}$. Phase III: alveolar plateau; measurement is slopeCO_2 together with end-tidal CO₂, PetCO_2 , or FetCO_2 .

$$V'_{\text{alv}} = f \cdot (V_t - V_{\text{Daw}})$$

Therefore, V'_{alv} is the pertinent parameter to measure ventilation.

Not all gas that enters the alveoli participates in gas exchange. Some gas ends up in non- or under-perfused lung spaces. To measure the efficiency of alveolar ventilation, PaCO_2 must be determined from an arterial blood gas sample. The ratio of mixed to ideal alveolar partial pressure is a measure of alveolar efficiency (Severinghaus 1957).

Normal values for V'_{alv} can be found in the literature or in Table E-1.

E.6 Capnogram shape (slope of the alveolar plateau, slopeCO₂)

The slope of the alveolar plateau (slopeCO₂) is a characteristic of the volumetric capnogram shape. This slope is measured in the geometric center of the curve, which is defined as the middle two quarters lying between V_{Daw} and the end of exhalation (Wolff 1989, Aström 2000). A steep slope is seen in COPD patients, while a flat plateau is seen in postoperative patients. A steep slope in normal patients may indicate a technical problem.

Normal values for slopeCO₂ can be found in the literature or in Table E-1.

Table E-1. Examples of "normal" or expected values in mechanically ventilated patients¹

Description	Unit ²	Normal	Reference
V_{Daw}	ml BTPS	2.2 ml/kg IBW	Radford 1954
slopeCO ₂	%CO ₂ /l	$31324 \cdot V_t - 1.535$	Aström 2000
V'_{CO_2} ³	ml/min STPD	2.6 to 2.9 ml/min/kg	Weissmann 1986 Wolff 1986
FetCO ₂ ⁴	%	5.1 to 6.1%	Wolff 1986

Table E-1. Examples of "normal" or expected values in mechanically ventilated patients¹ (continued)

Description	Unit ²	Normal	Reference
V'alv	mmHg (kPa)	36 mmHg (4.8 kPa)	Kiiski, Takala 1994
VD/Vt	ml/min BTPS	52 to 70 ml/min/kg actual body weight	⁵
VD/Vtbohr	--	Normal: 0.36 to 0.42 High: > 0.63 ±0.1	Kiiski, Takala 1994 Wolff 1986 Nuckton 2002
	--		⁶

1. These values are for illustration purposes and do not replace physician-directed treatment.
2. Bulk gas volumes such as minute ventilation and tidal volumes are usually measured in BTPS. Specific gas volumes are expressed in STPD. Conversion factors can be found in physics textbooks.
3. $V'CO_2 = V'alv * FetCO_2$
4. $FetCO_2 = PetCO_2 / (Pb - PH_2O)$
5. $V'alv = V'CO_2 / FetCO_2$ STPD
Lower value of normal range:
 $V'alv = 2.6 / 0.061 = 43 * ml * kg / min * STPD = 52 * ml * kg / min * BTPS$
Upper value of normal range:
 $V'alv = 2.9 / 0.051 = 57 * ml * kg / min * STPD = 70 * ml * kg / min * BTPS$
6. VD/Vtbohr is equivalent to VD/Vt if PetCO₂ is identical to PaCO₂. In normal lungs, this is the case. In diseased lungs, however, PetCO₂ and PaCO₂ are not identical. The classic example is pulmonary embolism.

E.7 Formulas

Alveolar tidal ventilation (V_{talv})

$$V_{talv} = V_t - V_{Daw}$$

Alveolar minute ventilation (V'_{alv})

$$V'_{alv} = f \cdot V_{talv}$$

Volume of CO₂ eliminated in one breath (V_{CO₂})

$$V_{CO_2} = V_e CO_2 - V_i CO_2$$

Fractional concentration of CO₂ in exhaled gas (F_{eCO₂})

$$F_{eCO_2} = V'_{CO_2} / \text{MinVol}$$

Partial pressure of CO₂ in exhaled gas (P_{eCO₂})

$$P_{eCO_2} = F_{eCO_2} \cdot (P_b - P_{H_2O})$$

Bohr dead space fraction (V_{Dbohr}/V_t) (Note: V_t in this formula needs to be in ml STPD)

$$V_{Dbohr}/V_t = 1 - (V_e CO_2 / (V_t \cdot F_{eCO_2}))$$

Physiological dead space fraction (V_D/V_t)

$$V_D/V_t = 1 - ((V_e CO_2 / V_t) / (p_a CO_2 / (P_b - P_{H_2O})))$$

E.8 References

- **Astrom E, Niklason L, Drefeldt B, Bajc M, Jonson B.** Partitioning of dead space – a method and reference values in the awake human. *Eur Respir J.* 2000 Oct; 16(4):659-664.
- **Brandi LS, Bertolini R, Santini L, Cavani S.** Effects of ventilator resetting on indirect calorimetry measurement in the critically ill surgical patient. *Crit Care Med.* 1999 Mar; 27(3):531-539.
- **Kiiski R, Takala J, Eissa NT.** Measurement of alveolar ventilation and changes in deadspace by indirect calorimetry during mechanical ventilation: a laboratory and clinical validation. *Crit Care Med.* 1991 Oct; 19(10):1303-1309.
- **Noe FE.** Computer analysis of curves from an infrared CO2 analyzer and screen-type airflow meter. *J Appl Physiol* 1963; 18:149-157.
- **Nuckton TJ, Alonso JA, Kallet RH, Daniel BM, Pittet JF, Eisner MD, Matthay MA.** Pulmonary dead-space fraction as a risk factor for death in the acute respiratory distress syndrome. *N Engl J Med.* 2002 Apr 25; 346(17):1281-1286.
- **Radford EP.** Ventilation standards for use in artificial respiration. *N Engl J Med* 1954; 251:877-883.
- **Severinghaus JW, Stupfel M.** Alveolar dead space as an index of distribution of blood flow in pulmonary capillaries. *J Appl Physiol* 1957; 10:335-348.
- **Weissman C, Kemper M, Elwyn DH, Askanazi J, Hyman AI, Kinney JM.** The energy expenditure of the mechanically ventilated critically ill patient. An analysis. *Chest.* 1986 Feb; 89(2):254-259.
- **Wolff G, Brunner JX, Weibel W, et al.** Anatomical and series dead space volume: concept and measurement in clinical practice. *Appl Cardiopul Pathophysiol* 1989; 2:299-307.
- **Wolff G, Brunner JX, Grädel E.** Gas exchange during mechanical ventilation and spontaneous breathing. Intermittent mandatory ventilation after open heart surgery. *Chest.* 1986 Jul; 90(1):11-17

F Low-pressure oxygen

CAUTION

- To reduce the risk of fire, use only hose systems approved for medical purposes and for use with oxygen between the oxygen source and ventilator.
- To reduce the risk of fire, do not use a low-pressure oxygen source that delivers a flow greater than 15 l/min.
- To reduce the risk of fire, ensure adequate ventilation at the rear of the ventilator.
- To reduce the risk of fire, switch off the oxygen source when the ventilator is not in a ventilating mode.
- To prevent possible patient injury when the ventilator is sourced from an oxygen concentrator, never operate the concentrator with a humidifier. Any humidifier system supplied with the concentrator must be drained or removed before using the ventilator.
- The ventilator's Oxygen control is not active when low-pressure oxygen is used. To prevent possible patient injury, use low-pressure oxygen only in cases where the low-pressure source can provide an adequate level of oxygenation.
- To prevent possible patient injury, ensure that an emergency backup oxygen supply (for example, a cylinder) is available in case the low-pressure oxygen source fails.
- To calibrate the O₂-cell disconnect all O₂ supplies. Calibration is done at 21%
- To prevent possible malfunction of the oxygen's control system, do not supply both high- and low-pressure oxygen to the ventilator simultaneously.

G Pneumatic diagram

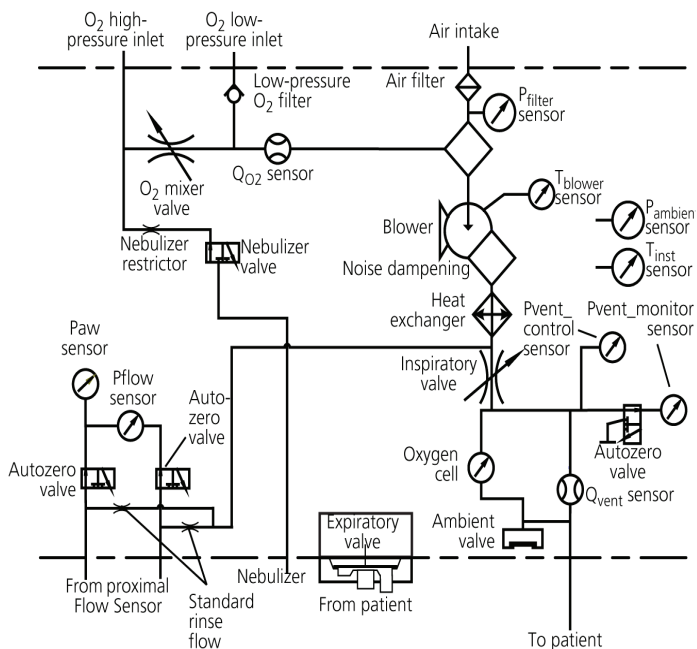


Figure G-1. Pneumatic diagram

H Parts and accessories

Table H-1 and Figure H-1 and Figure H-2 show the operator-replaceable HAMILTON-C2 parts. For additional parts and accessories, contact your HAMILTON MEDICAL representative.

NOTE:

Not all parts are available in all the markets.

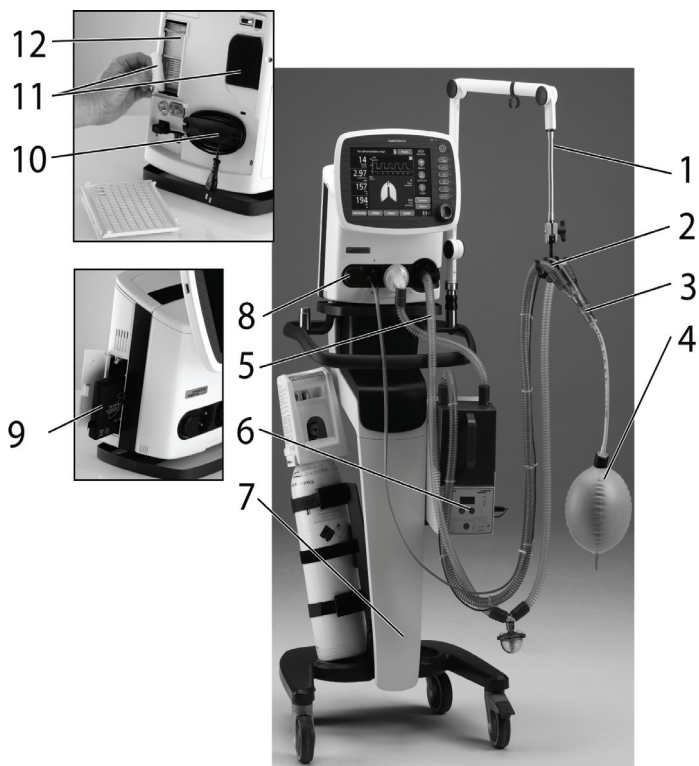


Figure H-1. Ventilator parts and accessoires - standard trolley

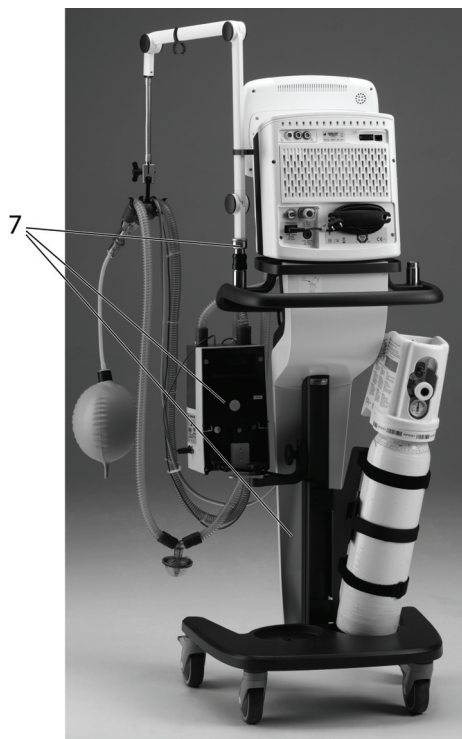


Figure H-2. Ventilator parts and accessoires - standard trolley.

Table H-1. Ventilator parts and accessories

Item no.	Description	Part no.
1	Support arm, HAMILTON-C2, for standard trolley	160153
2	Patient breathing set (see product catalog Humidifier and Breathing Circuits)	689692
3	Flow Sensor, pediatric/adult, single-patient use (package of 10)	279331
	Flow Sensor, pediatric/adult, reusable (package of 10) ¹	155362
	Flow Sensor, infant/neonatal, single-use (package of 10) ¹	155500
	CO2 sensors mainstream	
	HAMILTON CAPNOTAT-5™ CO2 sensor	281718
	CO2 adult airway adapter single-patient use, (package of 10) ¹	281719
	CO2 neonatal airway adapter single-patient use, (package of 10) ¹	281720
	CO2 adult airway adapter reusable, (package of 10) ¹	281721
	CO2 neonatal airway adapter reusable, (package of 10) ¹	281722
	15 mm male/female adapter for infant flow sensor, (package of 25) ¹	281803

Table H-1. Ventilator parts and accessories

Item no.	Description	Part no.
	CO2 sensor sidestream	
	CO2 sidestream sensor	281928
	CO2 sidestream adult/pediatric airway adapter single-patient use, (package of 10) ¹	281929
	CO2 sidestream pediatric/infant airway adapter single-patient use, (package of 10) ¹	281930
	CO2 sidestream adult/pediatric airway adapter w/dehumidification single-patient use, (package of 10) ¹	281931
	CO2 sidestream pediatric/infant airway adapter w/dehumidification single-patient use, (package of 10) ¹	281932
4	Demonstration lung assembly with endotracheal tube, 2 l, with 15 mm male x 22 mm male connector (adult)	151815
	Demonstration lung assembly with endotracheal tube, 0.5 l, with 15 mm male x 22 mm male connector (pediatric) ¹	151816
	Demonstration lung model, infant	R53353
5	Expiratory valve assembly, reusable (Includes Membrane, expiratory valve, reusable)	160245
	Inspiratory filter	279204
	Membrane, expiratory valve, reusable	160500
6	Humidifier (see product catalog Humidifier and Breathing Circuits)	689692

Table H-1. Ventilator parts and accessories

Item no.	Description	Part no.
7	Standard trolley	160150
	Humidifier support	160151
	Oxygen gas cylinder mounting kit	160152
	Quick-lock for tubing support arm	160154
	E-size cylinder holder	160505
8	Oxygen cell, HAMILTON-C2	396200
9	Battery (standard/optional)	369106
10	Power cord with US plug, 2-pin	355198
	Power cord with British angled-plug	355199
	Power cord with continental European plug, 2-pin	355200
11	Filter set (Includes 5 sets. Each set includes 2 air intake dust filters and 1 fan filter.)	160215
12	Filter, air intake (HEPA)	160216
	Cable, HAMILTON-C2 serial connector to computer, 2.5 m (8.2 ft). Shielded on male (ventilator) side only. ¹	160336
	Hose, high-pressure oxygen supply (white), 4 m ¹	281431

Table H-1. Ventilator parts and accessories

Item no.	Description	Part no.
	Language kit, English ¹	160010
	Language kit, German ¹	160011
	Language kit, Spanish ¹	160012
	Language kit, French ¹	160013
	Language kit, Italian ¹	160014
	Language kit, Russian ¹	160016
	Language kit, Chinese ¹	160017
	Language kit, Portuguese ¹	160018
	Battery charger/calibrator ¹	369104
	Car adapter for HAMILTON-C2	160187
	DISS diameter index safety standard	160470
	NIST no interchangeable screw thread	160471
	Coupling insert 4.8 mm ID for the low pressure O2 inlet	279913
	Extended warranty of 1 year	700403
	Extended warranty of 2 years	700404
	Extended warranty of 3 years	700405
	Bed mount with cylinder mount	160144
	Wall mount for bed mount	160145
	Universal bed mount kit	160148
	Quick-lock mounting plate	160466

Table H-1. Ventilator parts and accessories

Item no.	Description	Part no.
	Face mask with swivel elbow starter kit includes:	281754
	Face mask, size small	281751
	Face mask, size medium	281752
	Face mask, size large	281753
	Option board nurse call	160143
	Option board CO2, SpO2 and nurse call	160140
	Starter kit for nCPAP-PS	160057



Communications interface

I.1	Introduction	I-2
I.2	Patient monitor	I-2
I.2.1	Patient data management system (PDMS) or other computer system	I-4
I.2.2	Connector pin assignments	I-6
I.3	Nurse call	I-8
I.3.1	Inspiratory:expiratory (I:E) timing outlet	I-8
I.3.2	Remote alarm outlet	I-9
I.3.3	Connector pin assignments	I-10

I.1 Introduction

NOTE:

- All devices connected to the HAMILTON-C2 must be for medical use and meet the requirements of IEC 60601-1.
 - This interface includes an EMI-protective cover for the connector. When the connector is not in use, make sure the cover is installed.
 - HAMILTON-C2 can be used with Philips monitors and VueLink open interface.
-

The communications interface lets the HAMILTON-C2 send monitored data, ventilator settings, and alarms to a patient monitor, a patient data management system (PDMS), or other computer system through an RS-232 connector.

I.2 Patient monitor

CAUTION

To prevent possible patient injury when using a patient monitor, check the patient and the ventilator whenever the monitor reports a ventilator alarm. Not all monitors provide detailed alarm message information.

NOTE:

- Your monitor may not recognize and report all modes and parameters (for example, ASV mode, peak pressure monitoring parameter). It also may not recognize some specific alarms, but report them as general alarms. In such cases, HAMILTON MEDICAL recommends that you read the data directly from the HAMILTON-C2 screen.
 - Silencing the HAMILTON-C2's audible alarm does not automatically silence the audible alarm of the remote patient monitor.
 - To connect your HAMILTON-C2 to a monitor other than those described below, contact the monitor manufacturer.
-

With the communications interface, the HAMILTON-C2 ventilator can send data to various patient monitors.

Using the HAMILTON-C2 with a patient monitor requires the hardware shown in Figure I-1. Interfacing hardware specific to the manufacturers' monitors is listed in Table I-1. Order this interfacing hardware directly from the monitor manufacturer.

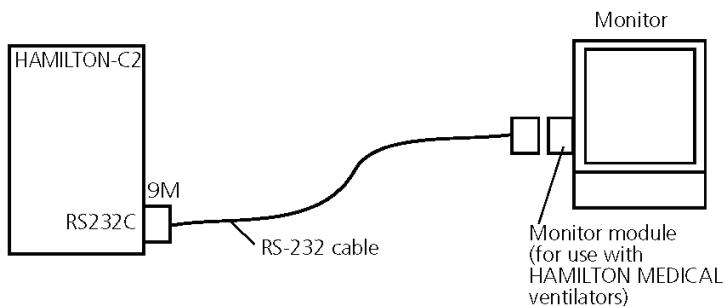


Figure I-1. HAMILTON-C2 connected to a patient monitor

Table I-1. Interfacing hardware for patient monitors

Manufacturer	Interfacing hardware required	Notes
Spacelabs Medical (GE Medical Systems)	Flexport converter and cable for HAMILTON MEDICAL ventilators	--
GE Marquette Medical Systems	Octanet and cable for HAMILTON MEDICAL ventilators	Tram-net is not compatible
Schiller	Cable for HAMILTON MEDICAL ventilators	--
Dräger Medical	MIB II Protocol Converter or MIB II Duo Protocol Converter and GALILEO MIB interface cable	For use with Infinity Modular Monitors (formerly Siemens Medical)
Nihon Kohden BSM-4100/5100 series bedside monitor	QI-407P interface	--

I.2.1 Patient data management system (PDMS) or other computer system

CAUTION

The computer connected to the HAMILTON-C2 should be for medical use only and meet the requirements of IEC 60601-1. Alternatively, a battery-powered laptop computers may be used. Do not connect other types of personal computer, because such computers do not fulfill the requirements of the standard. Consult a technical specialist or safety inspector in your hospital for more information.

The HAMILTON-C2 can transmit data from the ventilator to a PDMS or other computer system through its RS-232 connector. Data from the ventilator can ultimately be manipulated using software such as Microsoft® Excel. This is a useful tool for data management and clinical studies.

This application requires the hardware shown in Figure I-2. It also requires the DataLogger software and manual; contact your HAMILTON MEDICAL representative.

For more information about the communications protocol, contact HAMILTON MEDICAL.

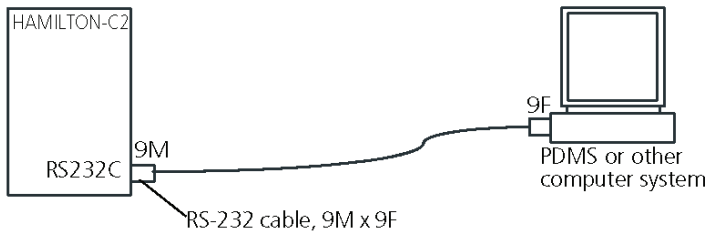


Figure I-2. HAMILTON-C2 connected to a computer system

Table I-2. Requirements for interfacing PDMSs

Manufacturer	Interfacing hardware required	Notes
Centricity® Critical Care Clinisoft care station	Centricity Ethernet box and cables	Formerly known as Datex-Ohmeda S/S CCIMS
Capsule Technologie PDMS	DataCaptor Device Interfaces (DDIs)	RS-232 to XML, HL7
iMDsoft® MetaVision Clinical Information System	Consult iMDsoft representative	--

I.2.2 Connector pin assignments

Figure I-3 shows the location of the RS-232 connector and its pinout.

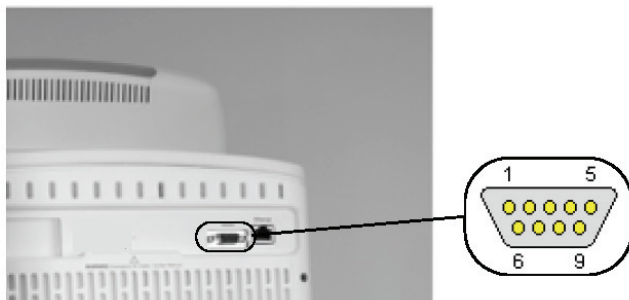


Figure I-3. RS-232 connector pinout

1	GND
2	RxD
3	TxD
4	DTR
5	GND (signal ground)
6	DSR
7	RTS
8	CTS
9	--
Shield	Chassis ground

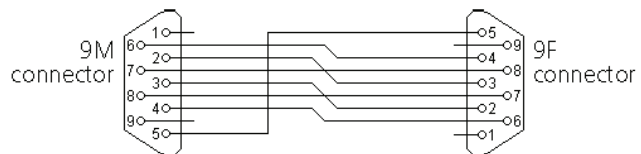


Figure I-4. RS-232 cable (PN 157354) wiring diagram

I.3 Nurse call

With the nurse call interface, the HAMILTON-C2 ventilator can control the ventilation of a patient and all alarms.

I.3.1 Inspiratory:expiratory (I:E) timing outlet

The I:E timing outlet lets your HAMILTON-C2 send I:E timing signals through the 6-pin (Special) connector. The maximum allowable voltage and current between the relay contacts are 48 V, 0.2 A.

This application requires the hardware shown in Figure I-5. Table I-3 lists the pin assignments for this connector. The I:E timing capability is based on a relay inside the ventilator.

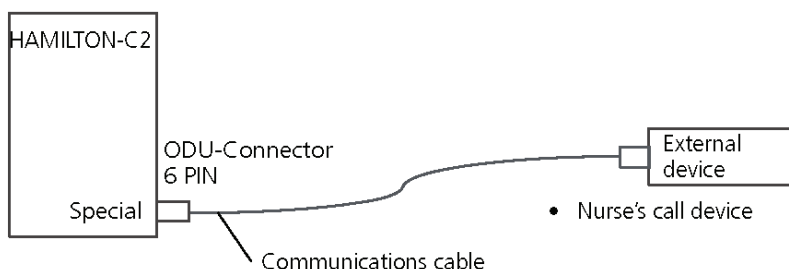


Figure I-5. HAMILTON-C2 connected to an external device through the Special connector

I.3.2 Remote alarm outlet

NOTE:

- Before operating the remote alarm function, make sure that the remote alarm function is operational.
 - If the remote alarm function is used in an isolation ward, regularly check that the remote alarm function is operational.
 - The maximum allowable voltage and current between the relay contacts are 48 V, 0.5 A.
-

The remote alarm (nurse's call) capability allows alarm conditions to be annunciated at locations away from the ventilator (for example, when the ventilator is in an isolation room). This application requires the hardware shown in Figure I-5. The HAMILTON-C2 sends alarm signals to a nurse's call device through the 6-pin ODU- connector. Table I-3 lists the pin assignments for this connector.

The HAMILTON-C2 alarm silence key silences the audible portions of the alarms at both the ventilator and the remote alarm device.

The remote alarm capability is based on a relay inside the ventilator. Figure I-6 shows the alarm and non-alarm positions for the relay. You can use either pins 3 and 2 or pins 3 and 1, depending on the logic of your nurse's call system (normally open or normally closed).

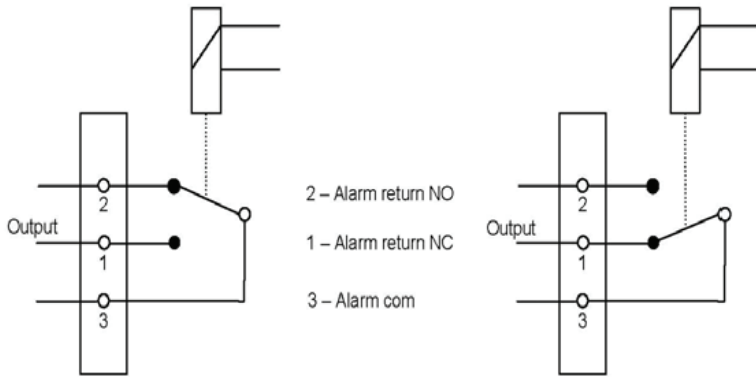


Figure I-6. Remote alarm relay positions

I.3.3 Connector pin assignments

Figure I-7 shows the locations of the interface connectors and pins. Table I-3 lists the pin assignments for these connectors.

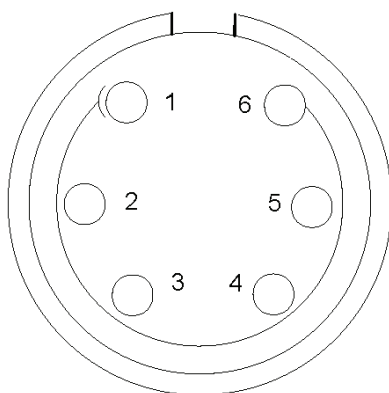


Figure I-7. Interface connectors

Table I-3. Interface connector pin assignments

PIN	Function	Description
1	Alarm return (normally closed)	normally closed Nurse Call relay contact 2
2	Alarm return (normally open)	normally open Nurse Call relay contact 1
3	Alarm common	Common relay contact Nurse Call
4	I:E common	I:E Contact:common
5	I:E Return (I-phase closed)	I:E Contact (I-phase closed)
6	Earth	Connection earth screen

J Configuration

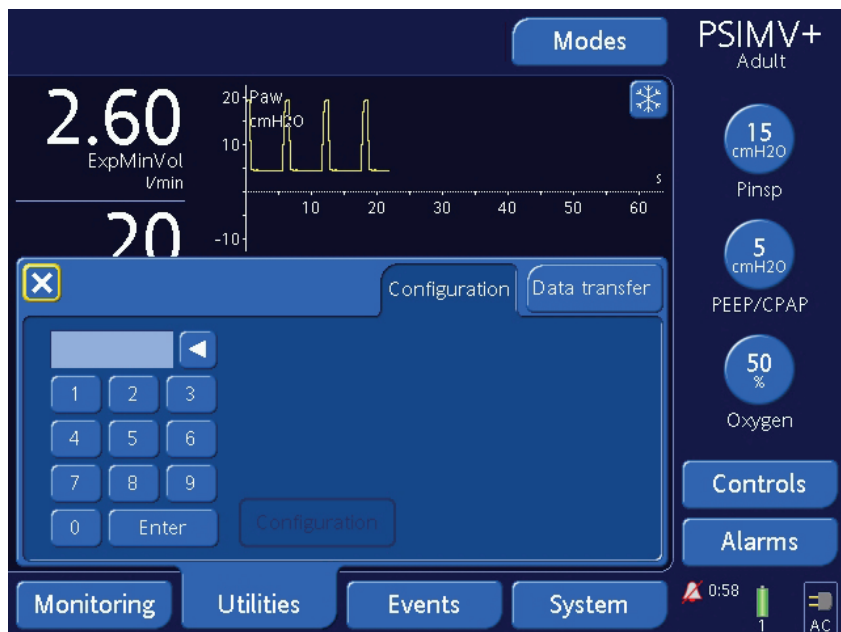
J.1	Introduction	J-2
J.2	Accessing configuration	J-2
J.3	General: Selecting the language, units of measure and oxygen source	J-3
J.3.1	Language: Selecting the default language	J-3
J.3.2	Units: Selecting the default unit of measure for pressure display, CO2 and length	J-3
J.3.3	More: Selecting the oxygen source and enabling the communications interface	J-4
J.4	Graphics window	J-5
J.4.1	MMP: Selecting the default main monitoring parameter display	J-5
J.5	Setup window (quick start-up settings)	J-6
J.5.1	Use setups: Define the default quick start-up settings	J-6
J.5.2	Use setups: Configure the quick start-up settings	J-7
J.6	Transfer window	J-12
J.7	Options windows	J-13

J.1 Introduction

During configuration, you set up the ventilator with a default language, main monitoring parameter display, startup settings for a new patient, and unit of measure for pressure. You also specify that oxygen will come from either a high- or low-pressure source, and you enable the communications interface.

J.2 Accessing configuration

Open the **Configuration** -> **Utilities** window with the **Utilities** tab. Enter the code "7132", confirm and select **Configuration**. Select the desired configuration function as described in the next subsections.



J.3 General: Selecting the language, units of measure and oxygen source

J.3.1 Language: Selecting the default language

Open the **General** -> **Language** window and select the desired language for screen display.

Select the naming of the volume controlled pressure adaptive modes (S)CMV+ / SIMV+ or APVcmv / APVsimv.



Figure J-1. Language configuration window

J.3.2 Units: Selecting the default unit of measure for pressure display, CO2 and length

Open the **General** -> **Units** window and select the unit of measure for pressure display, CO2 and length.



Figure J-2. Units configuration window

J.3.3 More: Selecting the oxygen source and enabling the communications interface

Open the **General** -> **More** window (Figure J-3).

Select the applicable oxygen source, **HPOMode** for high-pressure oxygen or **LPOmode** for low-pressure oxygen.

Enable or disable **Communications interface** (see Appendix I) as desired.



Figure J-3. More configuration window

J.4 Graphics window

J.4.1 MMP: Selecting the default main monitoring parameter display

Open the **Graphics** -> **MMP** window. Select the desired parameter to be displayed in that position on the screen. Repeat for the remaining parameters.

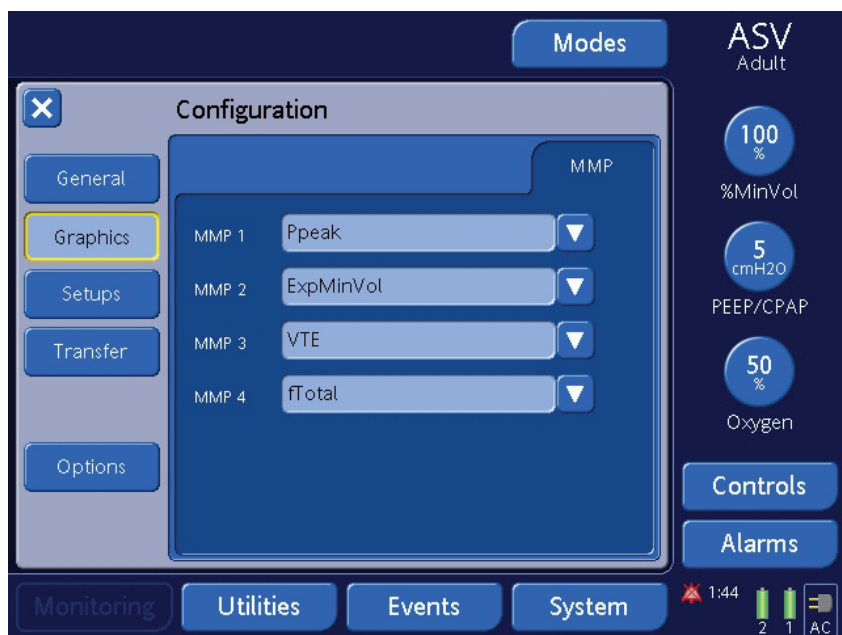


Figure J-4. MMP configuration window

J.5 Setup window (quick start-up settings)

J.5.1 Use setups: Define the default quick start-up settings

1. Through the **Setups** window (Figure J-5), open the **Default setup** window.
2. Select the desired default setup out of the list of default setups.

The default setup is the set up preposed by the HAMILTON-C2 after switching on the ventilator.

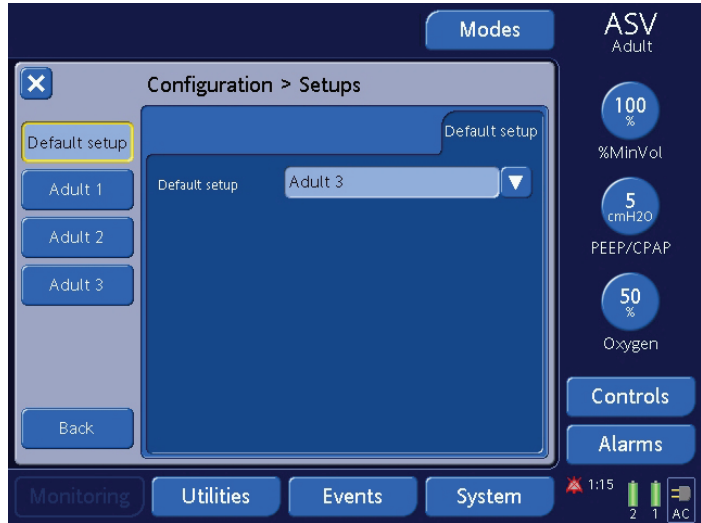


Figure J-5. Default setups configuration window

J.5.2 Use setups: Configure the quick start-up settings

1. Select (not in configuration) the desired ventilation pattern (i.e. mode, mode control settings and alarm settings)
2. Enter the configuration.
3. Open the **Setup** window (Figure J-6) and select the setup you like to configure
4. Rename the setup. Make sure to choose a significant name for your quick start-up setting. An empty quick start-up setting label will not be shown on the standby screen.
5. Store the selected settings by activating **Use current settings**.

To activate the quick start-up settings by the factory settings select **Use factory settings**.



Figure J-6. Setup > patient configuration window

6. Check patient parameter settings in **Mode Ctrl's** and set Vt/IBW manually. In **Vent status** set patient parameters manually too.

The **Vent Status** window (Figure J-10) configures the weaning zone ranges of the Vent Status intelligent panel (Figure J-11) according to your institution's protocol. Table A-14 lists the weaning zone ranges and defaults.



Figure J-7. Mode controls configuration window

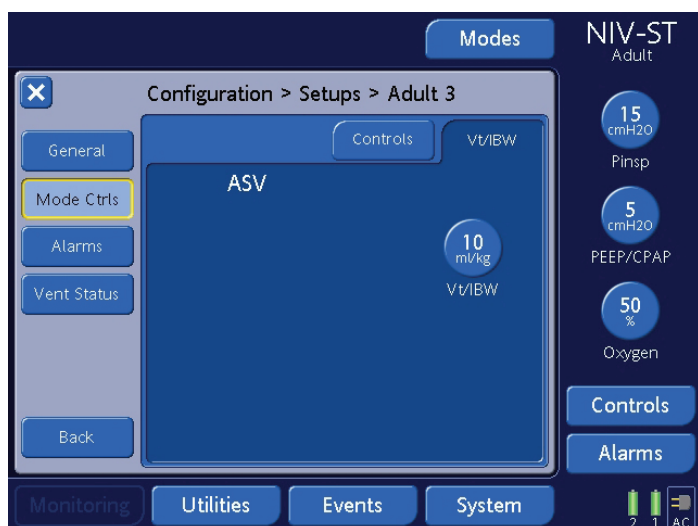


Figure J-8. Mode controls configuration window (Vt/IBW)



Figure J-9. Alarms configuration window



Figure J-10. Vent Status configuration window

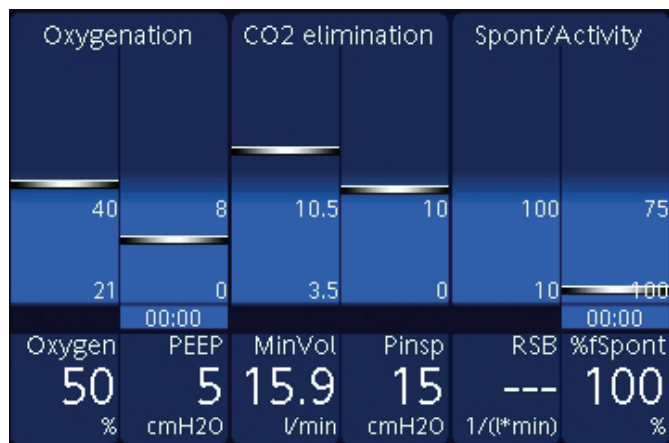


Figure J-11. Vent Status intelligent panel

7. Press **Back** button to return to the Default setup window. The next time the configured settings will be used by default.

J.6 Transfer window

1. Select **Import** or **Export** to transfer the configuration data with an USB stick.

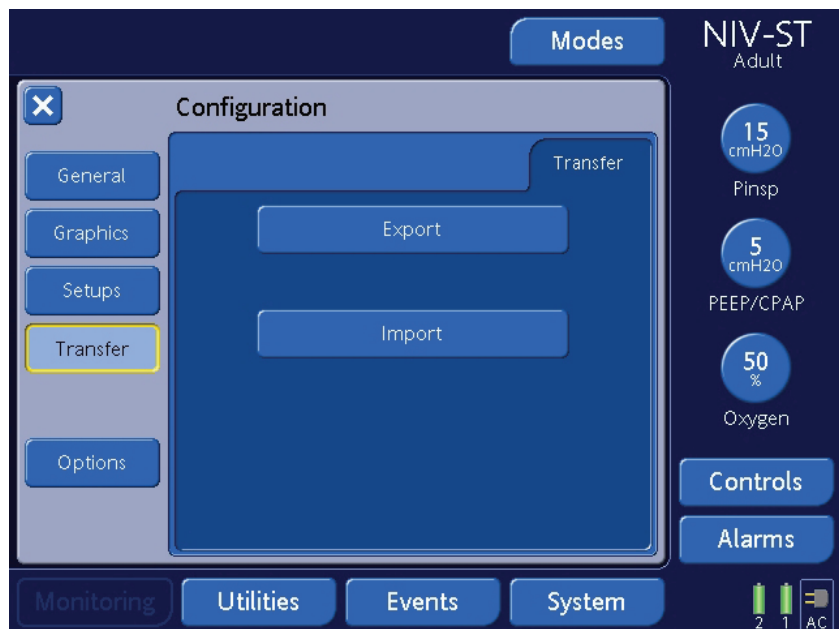


Figure J-12. Transfer window

J.7 Options windows

1. Select **Software** or **Hardware** options in the **Options** window to get information about the implemented software or hardware (Figure J-13 and Figure J-14).

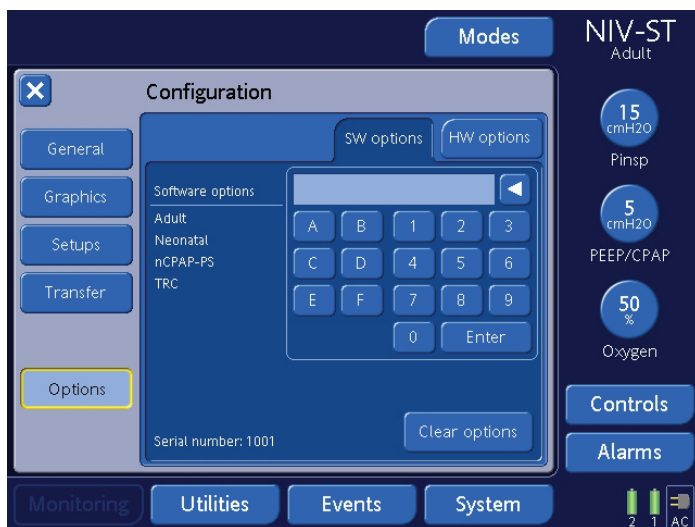


Figure J-13. Software options window

To implement software options enter acquired your code. For every options a different code is given to you. With the **Clear options** button the options can be deleted (a reboot is necessary).

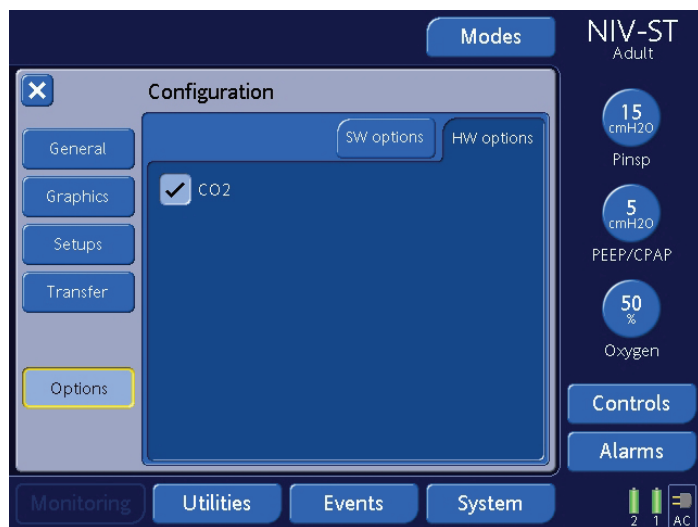


Figure J-14. Hardware options window

1. Activate the hardware options for identification.

Glossary

A	Ampere, a unit of current.
AC	Alternating current.
alarm buffer	Contains information on the four most recent alarm occurrences.
alarm lamp	Lamp atop the HAMILTON-C2 that lights in a color corresponding to the active alarm.
alarm silence key	Silences alarm sound for 2 min.
ambient state	An emergency state, in which the ventilator opens the ambient and expiratory valves and closes the inspiratory valves. This lets the patient breathe room air unassisted by the ventilator.
apnea	Cessation of breathing.
Apnea time	The maximum time allowed without a breath trigger, an alarm setting.
APRV	Airway Pressure Release Ventilation.
ASV target graphics panel	ASV graphical data representation, an Intelligent Panel.
ASV monitored data window	ASV numeric patient data, an Intelligent Panel.
ATPD	Ambient temperature and pressure, dry.
AutoPEEP	Unintended positive end-expiratory pressure, a monitored parameter.
Backup	Apnea backup ventilation.
backup buzzer	The buzzer designed to sound for at least 2 min as a back+up to the alarm speaker.
base flow	A continuous and constant gas flow from the inspiratory outlet to the expiratory outlet. It is essential for flow trigger.

b/min	Breaths per minute.
breathing circuit	Includes the inspiratory-expiratory tubing, humidifier, filters, and water traps.
bronchial tree	A part of the Dynamic Lung that shows resistance.
BTPS	Body temperature, barometric pressure at sea level, saturated with water vapor.
C	Compliance.
CE	A certification mark that indicates compliance with the Medical Device Directive, 93/42/EEC.
cm	Centimeter, a unit of length.
cmH ₂ O	Centimeters of water, a unit of pressure. 1 cmH ₂ O is approximately equal to 1 mbar, which equals 1 hPa.
CMV	Controlled mandatory ventilation.
communications interface	An option that lets you monitor the patient from a remote workstation.
COPD	Chronic obstructive pulmonary disease.
CPAP	Continuous positive airway pressure.
CSA	Canadian Standards Association.
Cstat	Static compliance, a monitored parameter.
DC	Direct current
dB(A)	Decibel, a unit of acoustic power.
DISS	Diameter index safety standard, a standard for high-pressure gas inlet fittings.
DuoPAP	Duo Positive Airway Pressure.
Dynamic Lung	An Intelligent Panel that visualizes tidal volume, lung compliance, patient triggering, and resistance in real-time.
E	Exhalation.
EMC	Electromagnetic compatibility.

EMI	Electromagnetic interference.
EN	European Norm, a European standard.
ET	Endotracheal.
ETO	Ethylene oxide.
ETS	Expiratory trigger sensitivity, a control setting.
event log	A record of clinically relevant ventilator occurrences, including alarms, setting changes, calibrations, maneuvers, and special functions since the ventilator was powered on.
Exp Flow	Peak expiratory flow, a monitored parameter.
ExpMinVol	Expiratory minute volume, a monitored parameter and alarm setting. In the Vent Status panel, ExpMinVol is the percentage of normal minute ventilation, based on IBW.
ExpMinVol NIV	Leakage compensation during non invasive ventilation.
f	Respiratory rate.
fControl	Mandatory breath frequency, a monitored parameter. It is displayed in monitored data window.
FetCO ₂	Fractional end-tidal CO ₂ concentration, a monitored parameter
FiO ₂	Fraction of inspired oxygen.
Flowtrigger	The patient's inspiratory effort that causes the ventilator to deliver a breath, a control setting.
fSpont	Spontaneous breathing frequency, a monitored parameter.
fTotal	Total breathing frequency, a monitored parameter and alarm setting.
ft	Foot, a unit of length.
Gender	Sex of patient, a control setting.
HEPA	High efficiency particle air filter
HME	Heat and moisture exchanger (artificial nose).

hPa	Hectopascal, a unit of pressure. 1 hPa is equal to 1 mbar, which is approximately equal to 1 cmH ₂ O.
HPO	High-pressure oxygen.
Hz	Hertz, or cycles per second, a unit of frequency.
I	Inspiration.
IBW	Ideal bodyweight.
ICU	Intensive care unit.
ID	Inner diameter.
IEC	International Electrotechnical Commission.
I:E	Inspiratory:expiratory ratio, a setting, timing parameter, and monitored parameter. Ratio of inspiratory time to expiratory time.
in.	Inch, a unit of length.
Insp Flow	Peak inspiratory flow, a monitored parameter.
inspiratory hold	A respiratory maneuver in which gas is retained in the patient's airways, often for X-raying purposes.
Intelligent Panel	A type of graphic display on the HAMILTON-C2. The Intelligent Panels include the Dynamic Lung, Vent Status, ASV target graphics panel, and ASV monitored data window panels.
IntelliTrig	Intelligent trigger, a feature that ensures that the set trigger sensitivity can trigger a breath independent from leakage and breath pattern.
IRV	Inverse ratio ventilation
ISO	International Organization for Standardization, a world-wide federation of national standards bodies.
kg	Kilogram, a unit of mass.
kPa	Kilopascal, a unit of pressure.
l	Liter, a unit of volume.
l/min	Liters per minute, a unit of flow.

lb	Pound, a unit of weight.
Leak	Leakage percent, a monitored parameter.
Loops	Special graphic type.
Loudness	Alarm loudness, a control setting.
LPO	Low-pressure oxygen.
LSF	Least squares fitting, a mathematical procedure for finding the best fitting curve to a given set of points by minimizing the sum of the squares of the offsets of the points from the curve.
m	Meter, a unit of length.
mandatory breath	A breath for which either the timing or size is controlled by the ventilator. That is, the machine triggers and/or cycles the breath.
manual breath	A user-triggered mandatory breath started by pressing the manual breath key.
%MinVol	Percentage of minute ventilation, a control setting in ASV mode.
MinVol	Minute volume, a calculated and monitored parameter used in ASV mode. Based on the operator-set %MinVol, the ventilator calculates the target MinVol in l/min, then measures and displays it in the ASV target graphics panel.
ml	Milliliter, a unit of volume.
ms	Millisecond, a unit of time.
MVLeak	Leakage compensation during non invasive ventilation.
MVSpont	Spontaneous expiratory minute volume, a monitored parameter.
MVSpont NIV	Leakage compensation during non invasive ventilation.
nCPAP-PS	Ventilation mode which applies nCPAP by nasal interfaces with reduced dead space on neonates.
NIST	Noninterchangeable screw thread, a standard for high-pressure gas inlet fittings.

NIV	Noninvasive ventilation, a ventilation mode.
NIV-ST	Spontaneous/timed noninvasive ventilation, a ventilation mode.
NPPV	Noninvasive positive pressure ventilation.
O ₂	Oxygen.
Oxygen	Oxygen concentration of the delivered gas, a control setting, monitored parameter, and, in LPO mode, an alarm setting.
Pasvlimit	Maximum pressure to be applied in ASV, a control setting.
Pat. height	A control setting. It is used to compute the patient's ideal body weight (IBW) in calculations for ASV and start-up settings.
Paw	Airway pressure.
PetCO ₂	Partial pressure of CO ₂
Pcontrol	Pressure control, a control setting in PCV+ mode. Pressure (additional to PEEP/CPAP) to be applied during the inspiratory phase.
PCV+	Pressure controlled ventilation
PDMS	Patient data monitoring system
PEEP/CPAP	PEEP (positive end-expiratory pressure) and CPAP (continuous positive airway pressure), a control setting and monitored parameter. PEEP and CPAP are constant pressures applied during both the inspiratory and expiratory phases.
Phigh	High pressure in APRV and DuoPAP mode
Pinsp	Inspiratory pressure, the target pressure (additional to PEEP/CPAP) to be applied during the inspiratory phase. It is operator-set in the PSIMV+ and NIV-ST and a displayed parameter in the Vent Status panel and the ASV target graphics panel.
Plow	Low pressure in APRV mode
Pressure	Maximum pressure allowed in the patient breathing circuit, an alarm setting.

Pmean	Mean airway pressure, a monitored parameter.
PN	Part number.
Ppeak	Peak airway pressure, a monitored parameter.
Pplateau	Plateau or end-inspiratory pressure. The pressure measured at the end of inspiration when flow is or is close to zero.
P-ramp	Pressure ramp, a control setting. The time required for the inspiratory pressure to rise to the set (target) pressure.
pressure control	Maintenance of a consistent transrespiratory pressure waveform despite changing respiratory system mechanics.
psi	Pounds per square inch, a unit of pressure.
PSIMV+	Pressure-controlled synchronized intermittent mandatory ventilation mode.
Psupport	Pressure support, a control setting valid during spontaneous breaths in SPONT, SIMV+, and NIV modes. Psupport is pressure (additional to PEEP/CPAP) to be applied during the inspiratory phase.
Rate	Breath frequency or number of breaths per minute, a control setting.
RCexp	Expiratory time constant, a monitored parameter.
Rinsp	Inspiratory flow resistance, a monitored parameter.
s	Second, a unit of time.
safety mode	An emergency state that ensures a basic minute ventilation while giving the user time for corrective actions in case of some technical fault alarms. The default inspiratory pressure is maintained, the expiratory valve opens as needed to switch system pressure levels between PEEP and inspiratory pressure, and patient sensing is nonfunctional.
(S)CMV+	Synchronized controlled mandatory ventilation mode.

sigh	Breaths delivered to deliberately increase tidal volume at a regular interval. If enabled, a sigh breath is delivered every 50 breaths with an additional 10 cmH ₂ O.
SIMV+	Synchronized intermittent mandatory ventilation mode.
SPONT	Spontaneous (pressure support) mode of ventilation.
spontaneous breath	A breath for which both the timing and size are controlled by the patient. That is, the patient both triggers and cycles the breath.
standby	The ventilator is in a waiting state, during which time there is no breath delivery.
STPD	Standard temperature and pressure, dry. Defined as gas at 0 °C (273 °K), barometric pressure at sea level and dry.
TE	Expiratory time, a monitored parameter.
technical fault	A type of alarm, resulting because HAMILTON-C2's ability to ventilate safely is questionable.
TF	Technical fault.
Thigh	Maximum time in APRV and DuoPAP mode
TI	Inspiratory time, a control setting and monitored parameter.
TI max	Maximum inspiratory time, a control setting in NIV and NIV-ST modes.
timv	SIMV breath interval.
ttrigger	Trigger window in SIMV modes.
Tlow	Minimum time in APRV mode
Trends	Special graphic type.
TRC	Tube resistance compensation
V	Volt, a unit of electric potential or volume.
VA	Volt-ampere, a unit of electric power.
VDaw	Airway dead space.

ventilator breathing system (VBS)	A breathing system bounded by the low-pressure gas input port(s), the gas intake port(s), and the patient connection port, together with the fresh-gas inlet and exhaust port(s), if fresh-gas inlet or exhaust ports are provided, as described in ISO 4135:2001.
Vent Status panel	An Intelligent Panel that visualizes six parameters related to the patient's ventilator dependency, including oxygenation, CO2 elimination and patient activity.
VLBW	Very Low Birth Weight
Vt	Tidal volume, a control setting, an alarm setting and a monitored parameter in the Vent Status panel.
VTE	Expiratory tidal volume, a monitored parameter. It is the integral of all negative flow measurements during exhalation.
VTE NIV	Leakage compensation during non invasive ventilation.
VTI	Inspiratory tidal volume, a monitored parameter.

Index

Numerics

100% O₂ function, details 9-5–??

100% O₂ key, description 1-14

A

Accessories

 general information 1-9–1-10

 specifications for compatible 1-11

Aeroneb Pro ultrasonic nebulizer system, how to install 2-26

Airway dead space. *See* VDaw

Airway pressure, mean. *See* Pmean

Alarm C-10

Alarm buffer 8-7–8-9

Alarm lamp, description 1-14

Alarm loudness window 4-26

Alarm silence key, description 1-15

Alarm tests 3-21–3-23

Alarms

 alarm buffer 8-7–8-9

 audible, specifications A-35

 how to respond to ??–8-20

 how to set 4-23–4-25

 loudness, how to adjust 4-25

 messages, list 8-10–8-21

 remote (nurse's call) outlet.

See Remote alarm outlet settings and definitions

 4-27–4-28

 settings and ranges, adjustable ??–A-28, A-29–A-30

 visual and audible indications 8-3

All events log 8-9–8-10

Alveolar minute ventilation. *See* V'alv

Alveolar tidal ventilation. *See* Vtalv

Ambient state 8-2, B-41

Apnea alarm 8-11

Apnea backup ventilation description 4-12–4-14

 how to enable/disable 4-10

Apnea time alarm setting, definition 4-27

Apnea ventilation alarm 8-11

Apnea ventilation ended alarm 8-11

ASV (adaptive support ventilation)

 references C-32

ASV (adaptive support ventilation)

 alarm settings ??–C-11

 detailed functional description C-15–C-26

 how to monitor patient ??–C-14

 initialization of ventilation ??–B-43, ??–C-32

 introduction C-2

 Otis' equation C-26–C-28

 target graphics window C-11, C-12

 use in clinical practice C-3–C-15

 weaning C-14–C-15

Autoclave sterilization, general guidelines 10-8

AutoPEEP monitored parameter, definition 6-15

B

Backup setting, definition 4-15

Backup ventilation. *See* Apnea backup ventilation

Base flow, specifications A-34

Batteries, backup

- description 2-30–2-32
- how to replace 10-13–??
- specifications A-4
- Battery 1 calibration required alarm 8-11
- Battery 1 temperature high alarm 8-12
- Battery 2 calibration required alarm 8-11
- Battery 2 temperature high alarm 8-12
- Battery low alarm 8-11
- Biphasic ventilation concept, description B-5–B-8
- Breath hold function 9-7
- Breathing circuit
 - how to install 2-6–2-16
 - ordering information H-3
 - specifications A-33
 - specifications for compatible 1-11
- Buffer, alarm 8-7–8-9

C

- Cell, oxygen. See Oxygen cell
- Check Flow Sensor alarm 8-12
- Check Flow Sensor tubing alarm 8-12
- Chemical disinfection, general guidelines 10-7–10-8
- Circuit, breathing. See Breathing circuit
- Cleaning, disinfection, and sterilization 10-2–10-6
- Cleaning, general guidelines 10-7

Clinical application of noninvasive ventilation ??–D-11

- CO₂ elimination. See V'CO₂
- CO₂ module
 - how to install 2-5–??
- CO₂ sensor
 - how to install 2-21–??, 2-24–??

- overview of operation 2-21
- CO₂ sensor calibration needed alarm 8-13
- CO₂ sensor disconnected alarm 8-13
- CO₂ sensor faulty alarm 8-13
- CO₂ sensor over temperature user message 8-13
- CO₂ sensor/adaptor zero calibration 3-13

Communications interface

option ??–I-7

- I:E timing outlet I-8
- remote alarm outlet (nurse's call), how to interface to GALILEO I-9–I-10
- RS-232 interface ??–I-5
- Compliance, static. See Cstat

Configuration J-6–J-11

- how to access J-2
- how to enable communications interface J-4–J-5
- how to establish start-up settings for new patient J-12–??
- how to select default language J-3
- how to select low- or high-pressure oxygen source J-4–J-5
- how to select main monitoring parameter (MMP) display J-5
- how to set units of measure J-3–J-4
- how to set weaning zone ranges for Vent Status panel ??–J-11
- specifications A-31–A-32
- Connectors
 - electrical power, location 1-16
 - gas supply, location 1-16
 - RS232, location 1-16

RS-232, pin assignments I-11
Connectors, specifications A-3
Control settings
 definitions 4-15–4-21
 how to adjust and confirm 4-8–4-12
 See also name of specific setting or Ventilator settings
Controls and indicators 1-13–1-15
 See also name of specific control or indicator
Cstat (static compliance) monitored parameter, definition 6-15
Curves. *See* Waveforms

D

Data Logger software, using to communicate with a computer I-5
Data transfer to USB memory device 3-19–3-20, ??–3-21
Date & time function 3-16–3-17
Dead space monitored parameter. *See* VDaw
Device temperature high alarm 8-14
Dimensions, ventilator A-2
Disconnection alarm 8-14
Disconnection on patient side alarm 8-14
Disconnection on ventilator side alarm 8-14
Disinfection, chemical, general guidelines 10-7–10-8
Dynamic Lung panel 7-2–??
 how to interpret compliance 7-3
 how to interpret resistance (R_{insp}) 7-4–??
 how to interpret tidal volume (V_t) 7-3
 patient triggering 7-4

E

Electrical specifications A-4
EMC declarations (IEC/EN 60601-1-2) A-37–A-41
End-expiratory pause pressure. *See* Pplateau
Endotracheal tube compensation 4-30–??
End-tidal CO₂ pressure. *See* PetCO₂
Environmental specifications A-3
ETS (expiratory trigger sensitivity) setting, definition 4-15
Event log 8-9–8-10
Exhalation obstructed alarm 8-14
Exhalation port occluded alarm 8-15
Exhaled CO₂ volume. *See* VeCO₂
Exp Flow (peak expiratory flow) monitored parameter, definition 6-15
Expiratory filter, using with the HAMILTON-G5 2-26
Expiratory flow. *See* Exp Flow
Expiratory minute volume. *See* ExpMinVol
Expiratory tidal volume. *See* VTE
Expiratory time constant. *See* RCexp
Expiratory time monitored parameter. *See* TE
Expiratory trigger sensitivity. *See* ETS
Expiratory valve cover and membrane
 how to install 2-14–2-15
 location 1-15
 maintenance 10-6
ExpMinVol (expiratory minute volume) alarm setting, definition 4-27

ExpMinVol (expiratory minute volume) monitored parameter, definition 6-16

ExpMinVol (Vent Status) parameter, definition 7-6

F

Fan failure alarm 8-15

Fan filter. See Filter, fan

fControl (mandatory breath rate) monitored parameter, definition 6-16

FetCO₂ (fractional end-tidal CO₂) monitored parameter definition 6-16

Filter

air intake (dust and HEPA), how to clean or replace 10-10-??

expiratory, using with the HAMILTON-G5 2-26

fan, how to clean or replace 10-10-??

inspiratory
particle size and efficiency A-33
specifications for compatible 1-11

Flex arm. See Support arm

Flow Sensor

calibration 3-11-??

description 1-7-1-8

how to install ??-2-16

location of connection 1-15

maintenance 10-4

part numbers H-3

Flow Sensor test ??-3-12

Flowtrigger setting, definition 4-16

Fractional end-tidal CO₂. See FetCO₂

Frequency

mandatory breath. See fControl

spontaneous breath. See fSpont

total breath. See fTotal

Frequency. See also Rate

From patient port, location 1-15

fSpont (spontaneous breath frequency) monitored parameter, definition 6-16

%fSpont (Vent Status) parameter, definition 7-7

fTotal (total respiratory rate) alarm setting, definition 4-27

fTotal (total respiratory rate) monitored parameter, definition 6-16

Function test. See Preoperational check

G

Gas mixing system, specifications A-3

Gas supply or Gas fitting. See Oxygen supply or fitting

Gender setting, definition 4-16

General information ??-1-23

Glossary ??-Glossary-9

Graphics

how to select second screen graphic 6-7-6-8

types 6-8-??

H

High frequency alarm 8-15

High minute volume alarm 8-15

High oxygen alarm 8-15

High PetCO₂ alarm 8-15

High pressure alarm 8-16

High pressure during sigh alarm 8-16

High tidal volume alarm 8-21

High-pressure oxygen supply, how to connect 2-32-2-33

Hold, inspiratory, how to perform 9-7

Humidifier

how to install 2-5
specifications for compatible 1-11

I

I:E (inspiratory:expiratory ratio)
monitored parameter, definition 6-16
I:E (inspiratory:expiratory ratio)
setting, definition 4-16
I:E timing outlet I-8
Insp Flow (peak inspiratory flow)
monitored parameter, definition 6-16
Inspiratory filter. See Filter, inspiratory
Inspiratory flow resistance. See Rinsp
Inspiratory tidal volume. See VTI
Inspiratory time monitored parameter. See TI
Inspiratory time setting. See TI
Inspired CO₂ volume. See ViCO₂
Installation
Aeroneb Pro nebulizer 2-26
breathing circuit 2-6–2-16
CO₂ module 2-5–??
CO₂ sensor 2-21–??, 2-24–??
expiratory valve cover and membrane 2-14–2-15
first-time, notes 2-3
Flow Sensor ??–2-16
humidifier 2-5
support arm 2-4
to electrical supply 2-27–2-28
to oxygen supply 2-32–2-33

Intelligent Panels

Dynamic Lung 7-2–??
Vent Status 7-5–7-6
IntelliTrig (intelligent trigger)
function D-9

Interface (communications) connector, location 1-16
Internal battery. See Batteries, backup
Intrinsic PEEP. See AutoPEEP
IRV alarm 8-16

K

Keypad, description 1-13–1-15
Knob, press-and-turn (P&T), description 1-15

L

Label, serial number 1-16
Lamp, alarm, description 1-14
Language, how to configure J-3
Leak (leakage percent) monitored parameter, definition 6-17
Leakage percent. See Leak
Least squares fitting (LSF) method 6-14
Logs. See Event log *or* Alarm buffer
Loss of external power alarm 8-16
Loss of PEEP alarm 8-17
Loudness setting, definition 4-16
Loudness, alarm, how to adjust 4-25
Low frequency alarm 8-17
Low minute volume alarm 8-17
Low oxygen alarm 8-17
Low PetCO₂ alarm 8-17
Low tidal volume alarm 8-21
LSF (least squares fitting) method 6-14

M

Main monitoring parameters (MMP) J-5
how to configure display J-5–J-6
location 1-21

Maintenance ??–10-15

preventive 10-9–10-15
 schedule 10-9–10-10
 Mandatory breath rate. *See* fControl
 Manual breath function, details 9-7
 Manual breath key, description 1-14
 Mask ventilation. *See* Noninvasive ventilation (NIV)
 Masks
 advantages and disadvantages of types in NIV D-5
 specifications for compatible 1-11
 Maximum inspiratory time. *See* TI max
 Maximum pressure alarm. *See* Pmax
 Mean airway pressure. *See* Pmean
 Messages, alarm, list 8-10–8-21
 Minute volume (expiratory)
 alarm setting or monitored parameter. *See* ExpMinVol
 Minute volume setting. *See* %MinVol
 %MinVol (% minute volume)
 setting, definition 4-17
 MMP. *See* Main monitoring parameters
 Mode additions
 tube resistance compensation (TRC) 4-29–4-31
Modes of ventilation ??–D-9
 control settings active in all modes A-12
 how to set 4-6–4-7
 Monitored parameters
 accuracies A-13–A-15, A-19–??
 definitions 6-15–6-23
 ranges and resolutions ??–A-15, A-19–??

See also name of specific parameter

Monitoring ??–6-23

Monitoring windows, how to access 6-2
 Mouthpiece, advantages and disadvantages for NIV D-6
 MVSpont (spontaneous minute volume) monitored parameter, definition 6-17

N

Nebulization function, details 9-8
 Nebulizer
 Aeroneb Pro, how to install 2-26
 specifications for compatible 1-11
 Nebulizer on/off key, description 1-15
 NIV mode, description B-13–B-14, B-17–B-19
 NIV. *See* Noninvasive ventilation
 NIV-ST mode, description B-19, B-23

Noninvasive ventilation (NIV)

adverse reactions D-5
 alarms D-7
 benefits of D-3
 checking mask fit and position D-9
 CO₂ rebreathing D-10
 contraindications D-4
 control settings ??–D-7
 maintaining PEEP and preventing autotriggering D-9
 monitored parameters D-8
 required conditions for use D-4
 selecting a patient interface D-5–D-6
 Numeric patient data, how to view 6-4–??

Nurse's call. See Remote alarm outlet

O

O₂ cell cal needed alarm 8-18
O₂ cell defective alarm 8-18
O₂ cell missing alarm 8-18
O₂ cell not system-compatible alarm 8-19
O₂ enrichment function, details ??-9-5
Operating hours, versions, options, and versions, how to view 3-6-3-7
Otis' equation C-26-C-28
Oxygen alarm setting, definition 4-27
Oxygen cell
 calibration 3-12-3-13
 maintenance 10-10
 part number H-5
Oxygen fittings, location 1-17
Oxygen monitored parameter, definition 6-17
Oxygen monitoring, how to enable/disable 3-15-??
Oxygen setting, definition 4-17
Oxygen supply failed alarm 8-19
Oxygen supply, how to connect 2-32-2-33
Oxygen (Vent Status) parameter, definition 7-6

P

Pasvlimit (ASV pressure limit) setting, definition 4-17
Pat. height (patient height) setting, definition 4-17
Patient breathing circuit. See Breathing circuit
Pause (end-expiratory) pressure. See Pplateau
Pcontrol (pressure control) setting, function and range 4-18

PCV+ mode, description B-11-B-13

Peak expiratory flow. See Exp Flow

Peak inspiratory flow monitored parameter. See Insp Flow

Peak proximal airway pressure. See Ppeak

PEEP (Vent Status) parameter, definition 7-6

PEEP/CPAP monitored parameter, definition 6-18

PEEP/CPAP setting, definition 4-18

PetCO₂ (end-tidal CO₂ pressure) alarm setting, definition 4-28

PetCO₂ (end-tidal CO₂ pressure) monitored parameter
 definition 6-18

Physiological dead space fraction at the airway opening. See VDaw/VTE

Piezo nebulizer. See Aeroneb Pro nebulizer system

Pinsp parameter, definition 6-19

Pinsp (Vent Status) parameter, definition 7-6

Plateau pressure. See Pplateau
Pmax (maximum pressure) alarm setting, definition 4-28

Pmean (mean airway pressure) monitored parameter, definition 6-19

Pneumatic specifications A-3
Port

 exhaust, location

 from patient, location 1-15

 See also Connector

 to patient, location 1-15

Power specifications A-4

Power switch, description 1-18

Ppeak (peak proximal airway pressure) monitored parameter, definition 6-19

Pplateau (plateau pressure)
 monitored parameter, definition 6-19
 P-ramp (pressure ramp) setting,
 definition 4-19
 Preoperational check 3-4–3-6
Preparing for ventilation ??–
 2-36
 Press-and-turn (P&T) knob, de-
 scription 1-15
 Pressure control setting. *See*
 Pcontrol
 Pressure limit has changed alarm
 8-19
 Pressure limitation alarm 8-19
 Pressure not released alarm 8-19
 Pressure ramp. *See* P-ramp
 Pressure support setting. *See*
 Psupport
 Pressure. *See name of specific*
 pressure
 Pressure. *See names of specific*
 pressure
 Preventive maintenance 10-9–
 10-15
 schedule 10-9–10-10
 Preventive maintenance re-
 quired alarm 8-19
 PSIMV+ mode, description B-19
 Psupport (pressure support) set-
 ting, function and range 4-20

R

Rate
 mandatory breath. *See*
 fControl
 spontaneous breath. *See* fS-
 pont
 total respiratory. *See* fTotal
 Rate setting, definition 4-20
 RCexp (expiratory time constant)
 monitored parameter, defini-
 tion 6-21

Relay, remote alarm (nurse's call)
 I-9, I-10
 Remote alarm outlet (nurse's
 call) I-9–I-10
 relay positions I-9, I-10
 Repacking and shipping 10-15
 Replace HEPA filter alarm 8-19
 Resistance, inspiratory flow. *See*
 Rinsp
Responding to alarms ??–8-20
 Rinsp (inspiratory flow resis-
 tance) monitored parameter,
 definition 6-21
 RS-232 interface ??–I-5
 connector, pin assignments
 I-6, I-11
 RSB (Vent Status) parameter,
 definition 7-7

S

Safety ventilation alarm 8-20
 Safety ventilation mode, descrip-
 tion 8-2
 Schedule of preventive mainte-
 nance 10-9–??
 (S)CMV+ mode, description B-8–
 B-11
 Screen. *See name of specific*
 screen
 Screenshot function. *See* Print
 screen function
 Sensor, Flow. *See* Flow Sensor
 Sensors on/off function 3-13–
 ??, 3-15–??
 Series dead space. *See* VDaw
 Setup, ventilator ??–2-36
 Shipping 10-15
 Sigh setting, definition 4-21
 Silence (alarm) key, description
 1-15
 SIMV+ mode, description B-19–
 B-23
 slopeCO2 (capnogram shape)
 monitored parameter

definition 6-21
 Software, DataLogger, using to communicate with a computer I-5
Special functions ??-9-8
Specifications
 alarms, settings and ranges, adjustable A-27-A-28, ??-A-30
 ASV C-28-C-30
 audible alarm A-35
 backup batteries A-4
 base flow A-34
 breathing circuit A-33
 configuration A-31-A-32
 connectors A-3
 dimensions, ventilator A-2
 electrical A-4
 environmental A-3
 gas mixing system A-3
 inspiratory filter, particle size and efficiency A-33
 monitored parameters
 accuracies A-13-A-15, A-19-??
 ranges and resolutions ??-A-15, A-19-??
 pneumatic A-3
 standards and approvals A-36
 ventilator settings, ranges, and resolutions A-8-A-11
 ventilator weight A-2
 SPONT mode, description B-13-B-16
 Spontaneous breath frequency. See fSpont
 Spontaneous minute volume. See MVSpont
 Standards and approvals A-36
 Standby, details 9-2
 Startup, ventilator 2-34-2-35
 Static compliance. See Cstat

Steam autoclaving, general guidelines 10-8
 Sterilization, steam autoclave, general guidelines 10-8
 Storage, requirements 10-15
 Support arm, how to install 2-4
 Switch, power, description 1-18
 Symbols, definitions 1-22-1-23
 Synchronized controlled mandatory ventilation mode. See (S)CMV+
 Synchronized intermittent mandatory ventilation mode. See SIMV+ or PSIMV+

T

TE (expiratory time) monitored parameter, definition 6-22
 Technical event alarm 8-20
 Technical fault alarm 8-20
 description 8-2, B-41

Tests and calibrations

Flow Sensor test ??-3-12
 tightness test ??-3-10

Tests, calibrations, and utilities ??-3-23

alarm tests 3-21-3-23
 CO₂ sensor/adaptor zero calibration 3-13
 data transfer to USB memory device 3-19-3-20, ??-3-21
 date and time function 3-16-3-17
 Flow Sensor calibration 3-11-??
 oxygen cell calibration 3-12-3-13
 preoperational check 3-4-3-6
 tightness test 3-9-??
 viewing operating hours, options, and versions 3-6-3-7
 when to run 3-2-3-3

- TI (inspiratory time) monitored parameter, definition 6-22
- TI (inspiratory time) setting definition 4-21
- TI max (maximum inspiratory time) setting, definition 4-21
- Tidal volume setting or alarm. See Vt
- Tightness test 3-9–3-10
- Time constant, expiratory. See RCexp
- Time, expiratory (monitored parameter). See TE
- Time, inspiratory (monitored parameter). See TI
- To patient port, location 1-15
- Total respiratory rate. See fTotal
- Tracheostomy tube compensation 4-29–4-31
- TRC setting, definition 4-22
- Trigger symbol, description 1-21
- Troubleshooting, alarms 8-10–8-21
- Tube resistance compensation (TRC), how to set up 4-29–4-31
- Turn the Flow Sensor alarm 8-21
- U**
- Ultrasonic nebulizer. See AeroNeb Pro ultrasonic nebulizer system
- Units of measure, how to configure J-3–J-4
- USB connector
 - how to transfer data via 3-19, ??–3-19
 - location 1-19
- Utilities
 - Flow Sensor test ??–3-12
 - tightness test ??–3-10
- V**
- V'alv (alveolar minute ventilation) monitored parameter
 - definition 6-22
- V'CO₂ (CO₂ elimination) monitored parameter
 - definition 6-22
- Valve, expiratory. See Expiratory valve
- VDaw (airway dead space) monitored parameter
 - definition 6-22
- VDaw/VTE (physiological dead space fraction at the airway opening) monitored parameter, definition 6-22
- VeCO₂ (exhaled CO₂ volume) monitored parameter, definition 6-22
- Vent Status panel 7-5–7-6
 - list of parameters 7-6
- Ventilator settings** ??–4-28,
??–4-28
 - ranges and resolutions A-8–A-11, ??–A-11
- ViCO₂ (inspired CO₂ volume) monitored parameter, definition 6-23
- Volume
 - alarm, how to adjust 4-25
 - expiratory minute. See Exp-MinVol
 - expiratory tidal (monitored parameter). See VTE
 - inspiratory tidal (monitored parameter). See VTI
 - leakage. See VLeak
 - spontaneous minute (monitored parameter). See MV-Spont
 - tidal. See Vt
- Vt (tidal volume) alarm setting, definition 4-28
- Vt (tidal volume) setting, definition 4-22

Vtalv (alveolar tidal ventilation)
monitored parameter, definition 6-23

VTE (expiratory tidal volume)
monitored parameter, definition 6-23

VTI (inspiratory tidal volume)
monitored parameter, definition 6-23

W

Warranty A-42-??

Waveforms, description 6-8–6-9

Weight, ventilator A-2

Window. *See name of specific window*

Window. *See name of specific window*

User Notes
